GEORGIA INSTITUTE OF TECHNOLOGY — OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

[x] ORIGINAL [ ] REVISION NO. ______

Project No. A-3597 — GTRI/~~GIT~~ — DATE 8/ 25/ 83

Project Director: H. Denny/E. Donaldson — ~~School~~/Lab ECSL/ECD

Sponsor: Georgia Power Company

Type Agreement: P.O. No. K-50024/Research Project Agreement A-3597

Award Period: From 7/8/83 To 3/8/84 (Performance) 3/8/84 (Reports)

Sponsor Amount:

	This Change	Total to Date
Estimated:	$	$ 122,531
Funded:	$	$ 122,531

Cost Sharing Amount: $ ______ Cost Sharing No: ______

Title: PAVE PAWS Interference Study (Revision 2 - Option I)

ADMINISTRATIVE DATA

OCA Contact Brian J. Lindberg Ext. 4820

1) Sponsor Technical Contact:

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Norcross, GA 30092

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Defense Priority Rating: NA

Military Security Classification: NA

(or) Company/Industrial Proprietary: NA

RESTRICTIONS

See Attached NA Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval — Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with Sponsor; however, none proposed.

COMMENTS:

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GEORGIA INSTITUTE OF TECHNOLOGY   OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 3/12/84

Project No. A-3597   ~~School~~/Lab ECSL/ECD

Includes Subproject No.(s)

Project Director(s) H. Denny/ E. Donaldson   GTRI / ~~GIT~~

Sponsor Georgia Power Company

Title PAVE PAWS Interference Study (Revision 2-Option I)

Effective Completion Date: 3/8/84 (Performance) 3/8/84 (Reports)

Grant/Contract Closeout Actions Remaining:

- [ ] None
- [x] Final Invoice ~~or Final Fiscal Report~~
- [ ] Closing Documents
- [ ] Final Report of Inventions
- [ ] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other

Continues Project No.   Continued by Project No.

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Form OCA 60:1028

Georgia Institute of Technology
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

2 September 1983

Georgia Power Company
107 Technology Park
Norcross, GA 30092

Attention: J. E. Thomas

Subject: Progress Report Nos. 1 and 2, Project A-3597
Report Period: 8 July 1983 to 31 August 1983
P. O. No. K-50024, "PAVE PAWS Interference Study."

Gentlemen:

The subject program was initiated on 8 July 1983. The overall objective of this program is to identify the potential for interference to Georgia Power communication systems from the "PAVE PAWS" radar system to be installed at Robins Air Force Base (Warner Robins, Georgia). The PAVE PAWS radar is a large phased array radar system which operates at very high RF power levels in the 420 to 450 MHz frequency range. Since the Georgia Power Company operates both a 450 MHz mobile radio network and a 6 GHz microwave link in the immediate vicinity of the proposed radar installation site, the potential exists for the radar system to cause interference to components of these two communications systems. The identification of potential interference problems is necessary to permit the Georgia Power company to take appropriate corrective actions prior to the installation of the PAVE PAWS system (the 1985-86 time frame).

To accomplish the above objective, program efforts will be directed to five major tasks:

(1) Evaluate available information to identify the operating characteristics and interference potential of the PAVE PAWS radar system.

(2) Perform interference susceptibility measurements on selected components of the 450 MHz mobile radio network.

(3) Perform interference susceptibility measurements on selected components of the 6 GHz microwave link.

(4) Perform analyses and computer simulations to predict the radar field intensity levels to which communication system components will be exposed and to assess the effects of these levels on the performance of the 450 MHz and 6 GHz communication systems.

(5) Document the results of the analytical investigations and experimental measurements along with conclusions and recommendations concerning the potential effects of PAVE PAWS on the two communications systems.

During this reporting period, efforts were directed primarily to the first two tasks. The search for pertinent information on the PAVE PAWS radar involved a visit to the Electromagnetic Compatibility Analysis Center (ECAC), Annapolis, Maryland, and telephone contacts with Dick Moore of the PAVE PAWS office at the U.S. Air Force Electronic Systems Division (ESD), and Jim Wade (PAVE PAWS Program Manager) and Jack Derube (System Engineer) at Raytheon. Approximately ten documents were obtained from ECAC which provide descriptive information on the PAVE PAWS radar, as well as assessments of potential interference problems. Also, a copy of the environmental assessment of the Southeast PAVE PAWS Radar System was obtained from Dick Moore of ESD. The information obtained from these documents and from the telephone contacts should be sufficient to approximate the electromagnetic environment to which the 450 MHz and 6 GHz systems will be exposed.

Under the second task, interference susceptibility measurements are being performed on selected components of the 450 MHz mobile communication network. Closed-system measurements (signals injected directly into the antenna terminals) are first being performed to determine the effects of various test parameters (receiver desired signal level, interference signal frequency, pulse width, and pulse repetition rates, etc.). Once the closed system measurements are completed and the test results evaluated, optimum test conditions and parameters will be defined and open-system (radiated) tests will be performed to define the susceptibility of the equiment to a radiated interference environment.

It is anticipated that interference susceptibility measurements on the components of the 450 MHz mobile radio network will be completed in early September, and that Task 3 (susceptibility measurements on 6 GHz components) ca be initiated shortly thereafter.

Respectfully submitted,

Ernest E. Donaldson
Project Director

Approved:

H. W. Denny, Chief
Electromagnetic Compatibility Division

Georgia Institute of Technology
ENGINEERING EXPERIMENT STATION
Atlanta, Georgia 30332

30 September 1983

Georgia Power Company
107 Technology Park
Norcross, GA 30092

Attention: J. E. Thomas

Subject: Progress Report No. 3, Project A-3597
Report Period: 31 August 1983 to 30 September 1983
P. O. No. K-50024, "PAVE PAWS Interference Study."

Gentlemen:

The subject program was initiated on 8 July 1983. The overall objective of this program is to identify the potential for interference to Georgia Power communication systems from the "PAVE PAWS" radar system to be installed at Robins Air Force Base (Warner Robins, Georgia). The PAVE PAWS radar is a large phased array radar system which operates at very high RF power levels in the 420 to 450 MHz frequency range. Since the Georgia Power Company operates both a 450 MHz mobile radio network and a 6 GHz microwave link in the immediate vicinity of the proposed radar installation site, the potential exists for the radar system to cause interference to components of these two communications systems. The identification of potential interference problems is necessary to permit the Georgia Power company to take appropriate corrective actions prior to the installation of the PAVE PAWS system (the 1985-86 time frame).

To accomplish the above objective, program efforts will be directed to five major tasks:

(1) Evaluate available information to identify the operating characteristics and interference potential of the PAVE PAWS radar system.

(2) Perform interference susceptibility measurements on selected components of the 450 MHz mobile radio network.

(3) Perform interference susceptibility measurements on selected components of the 6 GHz microwave link.

(4) Perform analyses and computer simulations to predict the radar field intensity levels to which communication system components will be exposed and to assess the effects of these levels on the performance of the 450 MHz and 6 GHz communication systems.

(5) Document the results of the analytical investigations and experimental measurements along with conclusions and recommendations concerning the potential effects of PAVE PAWS on the two communications systems.

During this reporting period, efforts were directed primarily to the second and fourth tasks. Under the second task, both closed system and open system susceptibility measurements were performed on two mobile units (MICOR and SYNTOR), a base station unit, and a repeater. Open-system measurements only were performed on two HANDIE-TALKIE units (HT-220 and MT-500). These measurements essentially complete the planned susceptibility tests on the 450 MHz equipment. However, other selected measurements may be performed as necessary at a later date to resolve specific questions related to the susceptibility characteristics of the 450 MHz system.

The measured susceptibility data have not yet been completely reduced to final form. However, Figures 1 through 3, which represent open-system (radiated) susceptibility data recorded on the SYNTOR mobile unit, base station, and HT-220 HANDI-TALKIE, respectively, provide an indication of the overall susceptibility characteristics of the 450 MHz system components. All data were recorded at the threshold of interference (level of interference signal required to produce detectable interference effects).

Several significant trends are evident in the above data. First, note that over the PAVEPAWS frequency range ($\approx$ 421 - 449 MHz), an interference threshold condition is reached (for essentially any frequency) for an interference signal field strength level (peak) of approximately +10 dBm/m^2 ($\approx$ 2 V/m). Second, note that as the interference signal frequency approaches the tuned frequency of the UHF receivers (e.g., 451.2 MHz), the susceptibility threshold generally decreases. This trend indicates that the interference condition will be caused primarily by the receiver response to the energy in the"skirts" of the pulsed signal spectrum. Only in a limited number of cases was interference due to "high power" effects noted (interference not dependent upon a unique relationship between the interference signal and receiver frequencies). Finally, note that all three receivers are sensitive to signals at their image frequencies. For example, the image response levels for the base station (Figure 2) and the HANDI-TALKIE (Figure 3) are approximately -35 dBm/M^2 (10 mV/m^2).

Under the fourth task, the potential interference environment in the area of the PAVE-PAWS radar site is being computed using an in-house propagation model (Longley-Rice model). Where the topography and constitutive parameters are known, the Longley-Rice model is capable of predicting field strength levels statistically over large areas as well as predicting field levels between distinct points in a region. In order to use the model, elevations along radial lines from the radar source are needed as input data.

Topographical maps (7.5 minute) were obtained from the U.S. Department of Geological Survey to cover a 25 mile radius around the PAVE-PAWS site. Radials were drawn every 15° and readings of the elevation were taken at one mile intervals along each radial. Constitutive parameters (surface refractivity, dielectric constant of earth, conductivity of earth) were obtained from a data base of such information in the Electronics and Computer Systems Laboratory.

From these input data, the Longley-Rice model precicts transmission loss relative to an isotropic radiator at given distances from the transmitter. This information, along with the radiation pattern of the radar (which is now being determined), will be used to compute the electric field strength at given positions throughout the region.

Plans for the next reporting period include the performance of susceptibility measurements on the 6 GHz microwave system and the completion of field strength estimates, at least in the vicinity of the repeater tower. Fairly firm conclusions as to the nature and severity of potential interference problems should thus be available sometime in mid to late October.

Respectfully submitted,

Ernest E. Donaldson
Project Director

Approved:

H. W. Denny, Chief
Electromagnetic Compatibility Division

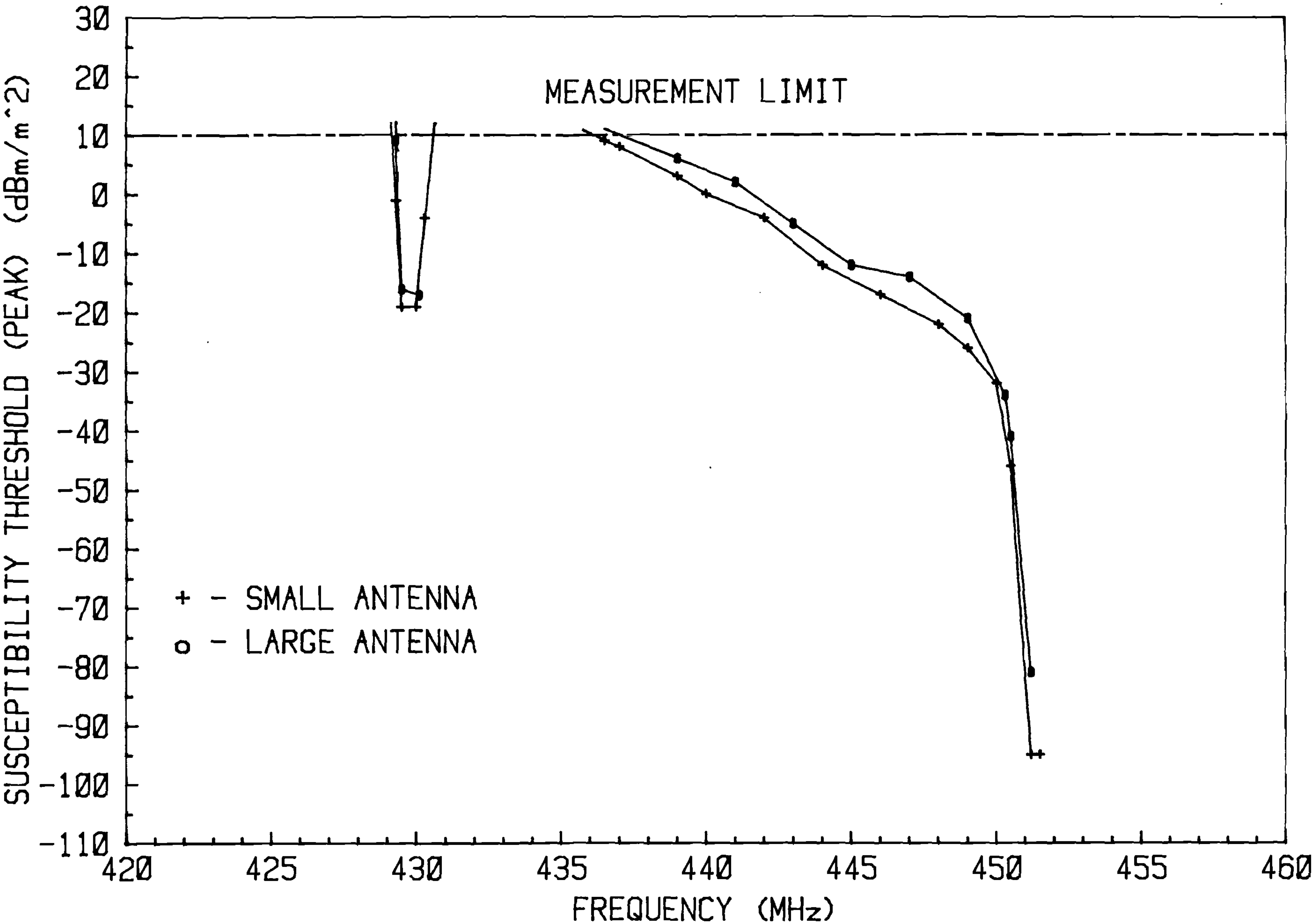

Figure 1. Open-system Interference Susceptibility Threshold Versus Frequency for SYNTOR Receiver.

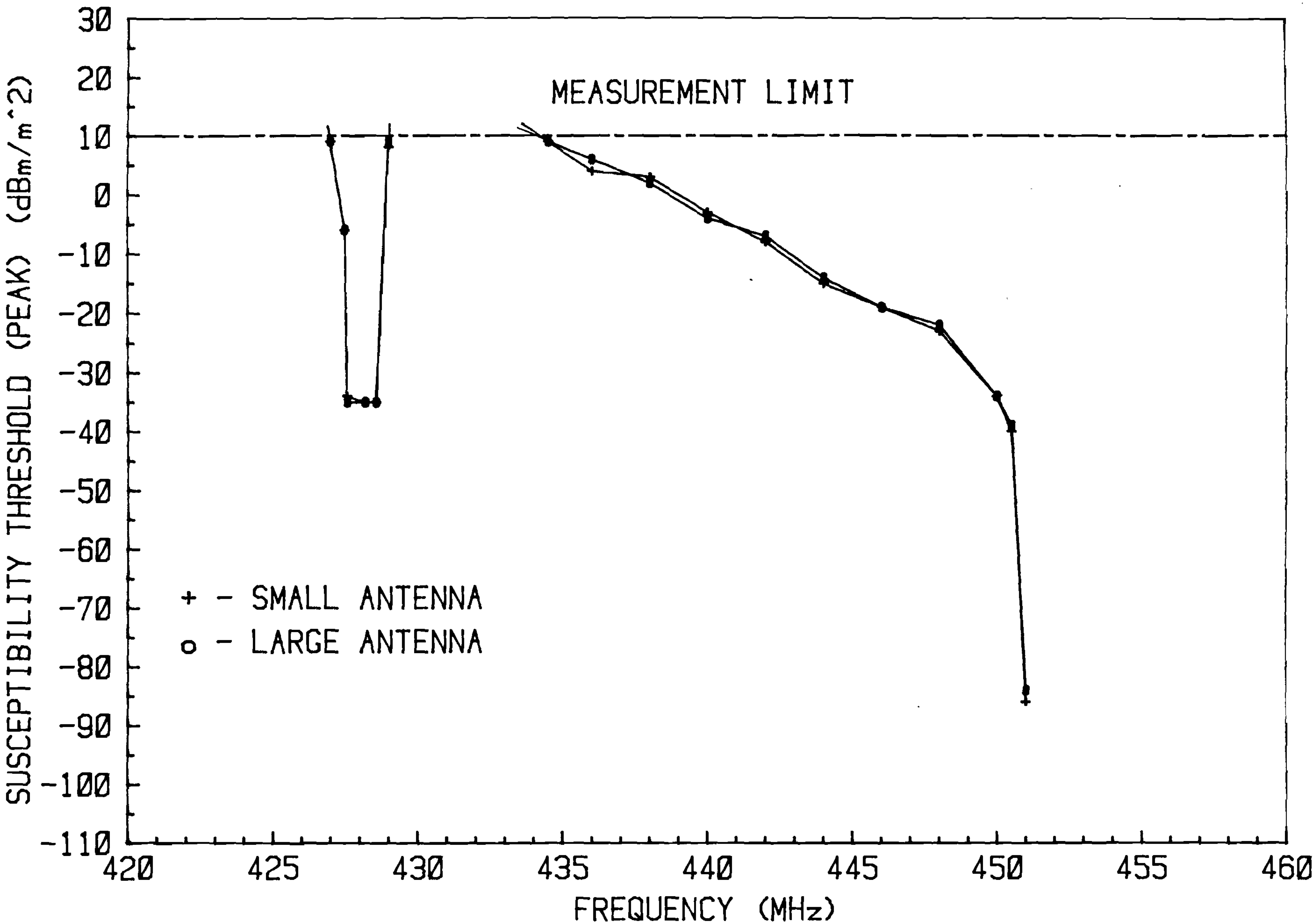

Figure 2. Open-system Interference Susceptibility Threshold Versus Frequency for Base Station Receiver.

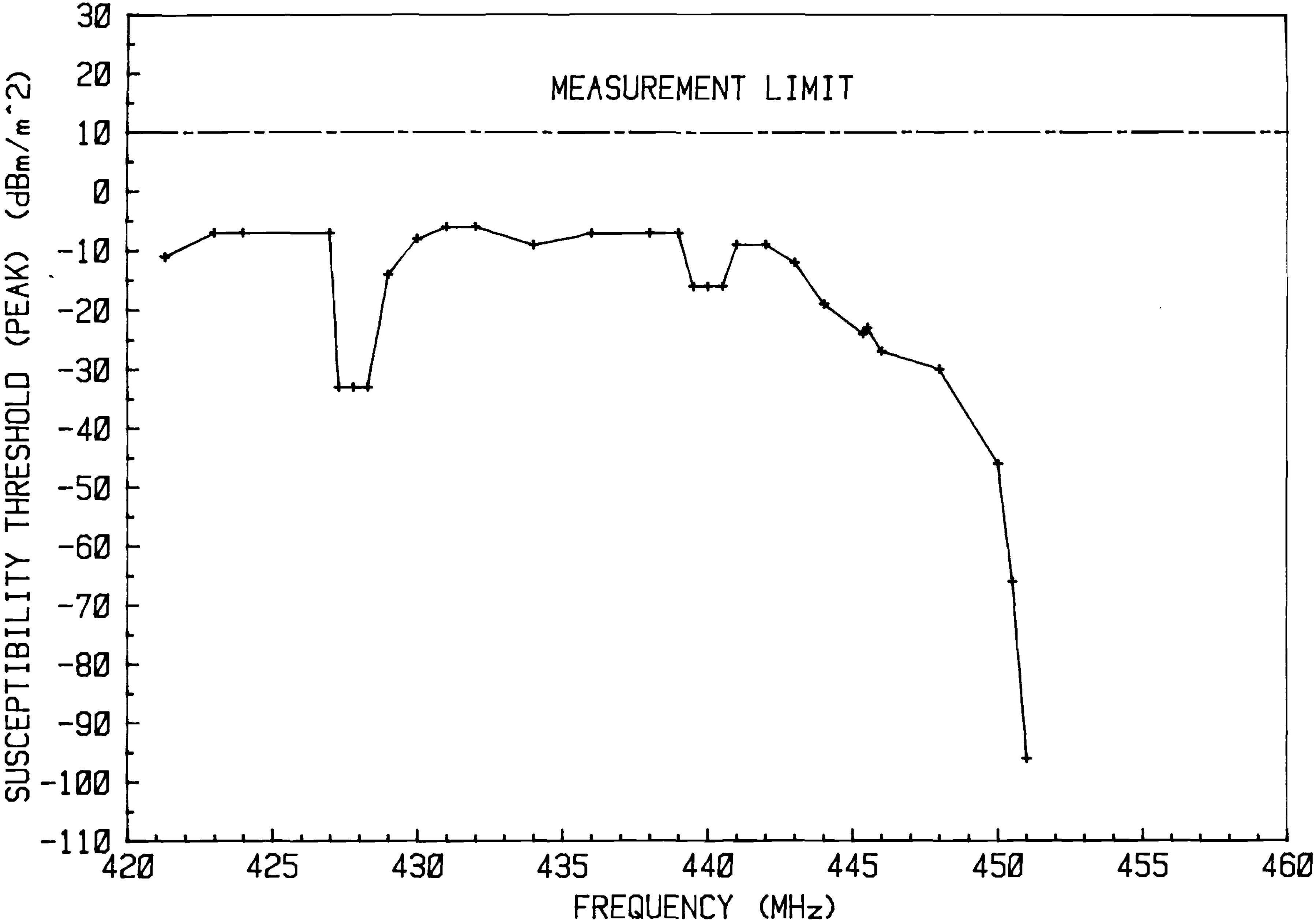

Figure 3. Open-system Interference Susceptibility Threshold Versus Frequency for HANDI-TALKIE HT-220.

Georgia Institute of Technology
ENGINEERING EXPERIMENT STATION
Atlanta, Georgia 30332

31 October 1983

Georgia Power Company
107 Technology Park
Norcross, GA 30092

Attention: J. E. Thomas

Subject: Progress Report No. 4, Project A-3597
Report Period: 30 September 1983 to 31 October 1983
P. O. No. K-50024, "PAVE PAWS Interference Study."

Gentlemen:

The subject program was initiated on 8 July 1983. The overall objective of this program is to identify the potential for interference to Georgia Power communication systems ... VS" radar system to be installed at
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(4) Perform analyses and computer simulations to predict the radar field intensity levels to which communication system components will be exposed and to assess the effects of these levels on the performance of the 450 MHz and 6 GHz communication systems.

(5) Document the results of the analytical investigations and experimental measurements along with conclusions and recommendations concerning the potential effects of PAVE PAWS on the two communications systems.

During this reporting period, efforts were directed primarily to the third and fourth tasks. Under the third task, radiated susceptibility measurements were performed on two major components of the 6 GHz microwave link -- a Collins receiver and a Granger Associates DTL 7300 Multiplexer. Susceptibility data were recorded in two basic test configurations. In one configuration, both the receiver and multiplexer were exposed to the 420 - 450 MHz field. In the second configuration, only the receiver was exposed to the interference field. For both configurations, susceptibility measurements were performed as a function of interference signal frequency, pulse width, pulse repetition frequency, and desired signal level. Interference thresholds (audio and data) were recorded on five receiver channels.

Figure 1 illustrates typical susceptibility data recorded on the receiver/multiplexer test configuration. Note that the lower interference frequencies produced the lowest thresholds, although threshold variations versus frequency generally did not exceed 6 - 8 dBm/m^2. The effects of pulse repetition frequency (PRF) are shown in Figure 2 for two different pulse widths. Somewhat suprisingly, the lower PRF's produced the lowest thresholds. This trend is attributed to transient changes in the level of the

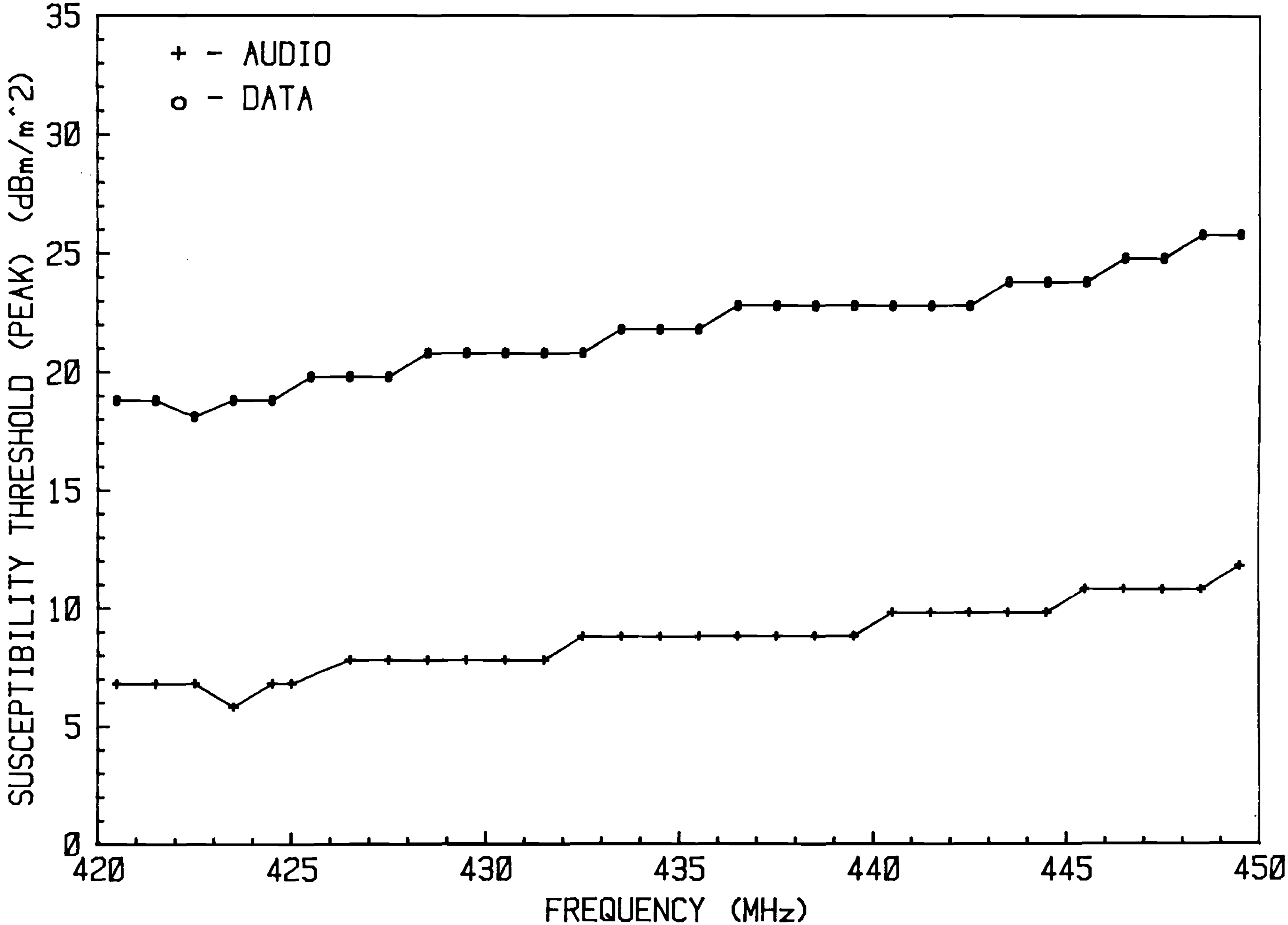


Figure 1. Susceptibility Threshold Versus Frequency for Receiver/ Multiplexer Radiated Channel G1 (4 - 8 kHz).

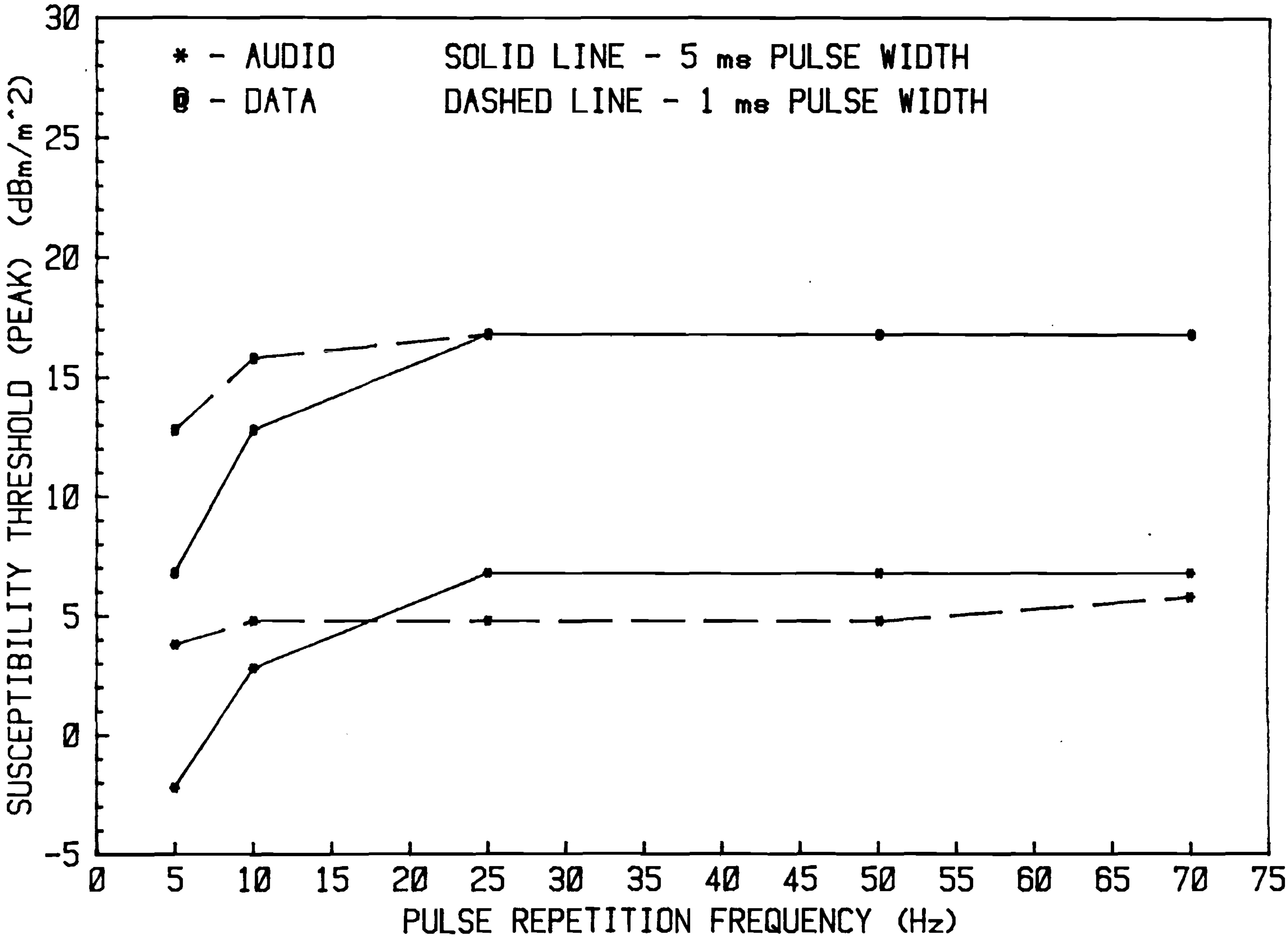


Figure 2. Susceptibility Threshold Versus Pulse Repitition Frequency for Receiver/Multiplexer Radiated -- Channel G1 (4 - 8 kHz).

interference field. Even at higher PRF's, it was noted that changes in the field strength (below threshold) caused momentary interference effects.

Efforts to compute the power density and electric field strength in the far field region around the PAVE PAWS radar continued this month.

The geographical area around PAVE PAWS was divided into six sectors of 60 degree coverage each. These areas were judged to be natural divisions based on the geographical similarity of the terrain in each region.

The contour data for each region was input to the Longley-Rice Area Model to determine the terrain statistics in the region and the transmission loss due to the effects of the terrain. These results were then used in conjunction with the PAVE PAWS antenna pattern data to compute the radiated power density and E-field strength at one-mile distances up to 25 miles from the radar. The effect of the terrain on the field strengths at any given distance from the source in any given sector is constant, and depends only on the average topography of the sector.

The field strength levels were determined at heights of 1.5 m and 105.2 m from average ground elevation. These calculations represent the field intensity at ground level and at the top of the tower. An example output of the computer program is given in Table I. These results are for the sector containing the Georgia Power radio tower with the main beam of the radar pointing in the direction of the tower. The fields in Table I are calculated at ground level (1.5 m). Power density is given in dBm/m^2 and the E-field is given in V/m as a function of distance. The three columns under power density and E are the levels for the cases where the elevation over the sector is taken to be the mean elevation minus two standard deviations, the mean elevation, and the mean elevation plus two standard deviations, respectively. The main beam of the radar is at a 3^{o} elevation.

Field strength data similar to that of Table I is now being assembled for all sectors around the radar, for both ground level and top of tower.

TABLE I

POWER DENSITY AND ELECTRIC FIELD

STRENGTH IN SECTOR AROUND GEORGIA POWER

TOWER

DISTANCE(KM)	POWER DENSITY (dBm/m^2)			E(V/m)		
	$\overline{X}-2\sigma$	$\overline{X}$	$\overline{X}-2\sigma$	$\overline{X}-2\sigma$	$\overline{X}$	$\overline{X}+2\sigma$
1.600	22.310	28.483	39.262	8.010E+00	1.631E+01	5.640E+01
3.200	16.642	16.642	22.883	4.171E+00	4.171E+00	8.557E+00
4.800	11.420	11.420	16.779	2.286E+00	2.286E+00	4.238E+00
6.400	7.621	7.621	11.021	1.476E+00	1.476E+00	2.184E+00
8.000	4.483	4.483	6.034	1.029E+00	1.029E+00	1.230E+00
9.700	1.809	1.809	1.809	7.562E-01	7.562E-01	7.562E-01
11.300	-.417	-.417	-.417	5.852E-01	5.852E-01	5.852E-01
12.900	-2.567	-2.567	-2.567	4.569E-01	4.569E-01	4.569E-01
14.500	-4.483	-4.483	-4.483	3.665E-01	3.665E-01	3.665E-01
16.100	-6.192	-6.192	-6.192	3.010E-01	3.010E-01	3.010E-01
17.700	-7.815	-7.815	-7.815	2.497E-01	2.497E-01	2.497E-01
19.300	-9.466	-9.466	-9.466	2.065E-01	2.065E-01	2.065E-01
20.900	-10.958	-10.958	-10.958	1.739E-01	1.739E-01	1.739E-01
22.500	-12.299	-12.299	-12.299	1.490E-01	1.490E-01	1.490E-01
24.100	-13.596	-13.596	-13.596	1.283E-01	1.283E-01	1.283E-01
25.700	-14.954	-14.954	-14.954	1.098E-01	1.098E-01	1.098E-01
27.400	-15.910	-15.910	-15.910	9.832E-02	9.832E-02	9.832E-02
29.000	-16.903	-16.903	-16.903	8.770E-02	8.770E-02	8.770E-02
30.600	-17.970	-17.970	-17.970	7.757E-02	7.757E-02	7.757E-02
32.200	-18.912	-18.912	-18.912	6.959E-02	6.959E-02	6.959E-02
33.800	-19.934	-19.934	-19.934	6.187E-02	6.187E-02	6.187E-02
35.400	-20.835	-20.835	-20.835	5.577E-02	5.577E-02	5.577E-02
37.000	-21.719	-21.719	-21.719	5.037E-02	5.037E-02	5.037E-02
38.600	-22.587	-22.587	-22.587	4.558E-02	4.558E-02	4.558E-02
40.200	-23.440	-23.440	-23.440	4.132E-02	4.132E-02	4.132E-02

These data, in conjunction with the measured susceptibility characteristics of UHF and microwave system components, will provide a basis for assessing potential PAVE PAWS related interference problems and possible problem resolutions.

Respectfully submitted,

Ernest E. Donaldson
Project Director

Approved:

H. W. Denny, Chief
Electromagnetic Compatibility Division

Georgia Institute of Technology
ENGINEERING EXPERIMENT STATION
Atlanta, Georgia 30332

30 November 1983

Georgia Power Company
107 Technology Park
Norcross, GA 30092

Attention: J. E. Thomas

Subject: Progress Report No. 5, Project A-3597
Report Period: 30 October 1983 to 30 November 1983
P. O. No. K-50024, "PAVE PAWS Interference Study."

Gentlemen:

The subject program was initiated on 8 July 1983. The overall objective of this program is to identify the potential for interference to Georgia Power communication systems from the "PAVE PAWS" radar system to be installed at Robins Air Force Base (Warner Robins, Georgia). The PAVE PAWS radar is a large phased array radar system which operates at very high RF power levels in the 420 to 450 MHz frequency range. Since the Georgia Power Company operates both a 450 MHz mobile radio network and a 6 GHz microwave link in the immediate vicinity of the proposed radar installation site, the potential exists for the radar system to cause interference to components of these two communications systems. The identification of potential interference problems is necessary to permit the Georgia Power company to take appropriate corrective actions prior to the installation of the PAVE PAWS system (the 1985-86 time frame).

To accomplish the above objective, program efforts will be directed to five major tasks:

(1) Evaluate available information to identify the operating characteristics and interference potential of the PAVE PAWS radar system.

(2) Perform interference susceptibility measurements on selected components of the 450 MHz mobile radio network.

(3) Perform interference susceptibility measurements on selected components of the 6 GHz microwave link.

(4) Perform analyses and computer simulations to predict the radar field intensity levels to which communication system components will be exposed and to assess the effects of these levels on the performance of the 450 MHz and 6 GHz communication systems.

(5) Document the results of the analytical investigations and experimental measurements along with conclusions and recommendations concerning the potential effects of PAVE PAWS on the two communications systems.

During this reporting period, efforts were directed primarily to the fourth task. Although this task has not yet been completed, some examples of preliminary assessments of the potential effects of the PAVE PAWS signal on the 450 MHz and 6 GHz communication systems are summarized below.

Computations of field strength levels at the Georgia Power radio tower show that the (worst-case) power density at ground level (1.5 meters above ground) and at the top of the tower will be approximately 14 dBm/m^2 and 49 dBm/m^2, respectively. When these predicted power density levels are compared to the susceptibility levels recorded on the test specimen UHF and microwave equipment, the likelihood of interference can be identified. For example, Figure 1 shows radiated susceptibility levels versus frequency recorded on one channel of the microwave receiver/multiplexer (for a pulse width of 5 ms and a pulse repetition frequency of 70 Hz). Note from this figure that a 14 dBm/m^2 power density level would likely cause audio interference at any frequency in the PAVE PAWS frequency band. On the other hand, this figure shows that interference to the data stream would be unlikely since the lowest data threshold over the 420 - 450 MHz frequency range is approximately 18 dBm/m^2 (at 422 MHz).

Although the above example definitely indicates that audio interference could occur in the microwave system, the extent of such interference will depend upon the results of evaluations of other susceptibility data recorded in the microwave system components (susceptibility data for other channels, effects of pulse width and pulse repetition frequency, etc.). Moreover, it is important to recognize that the above example does not account for such factors as the shielding provided by the structure which houses the microwave receiver and multiplexer. Hence firm conclusions as to whether microwave interference problems will occur cannot be drawn until evaluations and analyses of all pertinent information have been completed.

Assessments of potential interference problems for the UHF mobile radio network are complicated by the fact that interference may occur due to three different mechanisms: (1) co-channel interference caused by the "skirt" of the PAVE PAWS spectrum; and (2) spurious responses caused by undesired mixes between the PAVE PAWS spectrum (center frequency) and the local oscillator signal in the UHF receivers; and (3) "high power" interference caused by the peak energy at the center frequency of the PAVE PAWS spectrum. Interference assessments for the VHF receivers are further compounded by the fact that the PAVE PAWS signal may be coupled to the receivers via the antenna, by case radiation, or a combination of these two routes. For example, Figure 2 shows the radiated susceptibility thresholds for the UHF repeater with no antenna. Note that for frequencies near 449 MHz, the receiver exhibits a susceptibility threshold of approximately 0 dBm/m^2 (due to pickup of the skirts of the radar signal spectrum). This susceptibility threshold is roughly 14 dB lower than the predicted field strength (+14 dBm/m^2) at the base of the repeater tower. Also note that a receiver spurious response occurs (at approximately 433 MHz) whose threshold level (-10 dBm/m^2) is 24 dB below the predicted field strength.

Although the above example shows that case radiation problems may occur for the UHF repeater, such problems could possibly be resolved through better shielding of the receiver case or housing structure. However, preliminary calculations have shown that severe interference problems may be caused by antenna coupled interference signals, for two reasons. The first reason is that the repeater antenna will be exposed to a relatively high PAVE PAWS field strength level (49 dBm/m^2). The second reason is that the repeater antenna/ transmission line are designed to operate at the frequency of this field and hence will readily couple the interference signal to the receiver input.

As an example of potential interference problems caused by antenna coupled signals, consider the level of signal coupled to the receiver antenna terminal from a 49 dBm/m^2 field. Assuming an antenna gain of 10 dB and cable losses of 1 dB, the power in dBm coupled to the antenna terminals will be approximately +43 dBm as determined from

$$P_R = \frac{P_D \, G_R \, \lambda^2}{4\pi}$$

where,

P_R = Power Received
P_D = Power Density (+49 dBm/m^2)
G_R = Antenna Gain + Cable Loss (+9 dB)
λ = Wavelength (λ^2 = -3.5 dB relative to 1 meter)
4π = Constant (-11 dB).

When a received level of +43 dBm at the receiver is compared to the repeater closed system susceptibility data of Figure 3, it is evident that the potential exists for severe interference problems in the receiver. Note from this figure that at a frequency of 449 MHz, the repeater will be susceptible to antenna coupled signals as low as -30 dBm. Thus for a signal which is 73 dB (43 dB + 30 dB) above this susceptibility threshold, it is likely that severe interference problems will occur within the UHF repeater.

The above examples of interference to the UHF repeater are to be considered preliminary since analyses/evaluations of PAVE PAWS interference to the UHF communication network ware still underway. Moreover, these examples were based on susceptibility data derived from laboratory-generated PAVE PAWS spectrum characteristics. The actual PAVE PAWS spectrum characteristics, which are currently under investigation, will likely be somewhat different and hence yield different results. However, such differences will definitely not cause a 73 dB reduction in the level of PAVE PAWS signal coupled to the receiver antenna port. Thus it is concluded that significant interference to the VHF repeater will be experienced unless appropriate corrective actions are taken.

Plans for the coming month include a continuation of interference assessments and the initiation of efforts to document the program activities and results.

Respectfully submitted,

Ernest E. Donaldson
Project Director

Approved:

H. W. Denny, Chief
Electromagnetic Compatibility Division

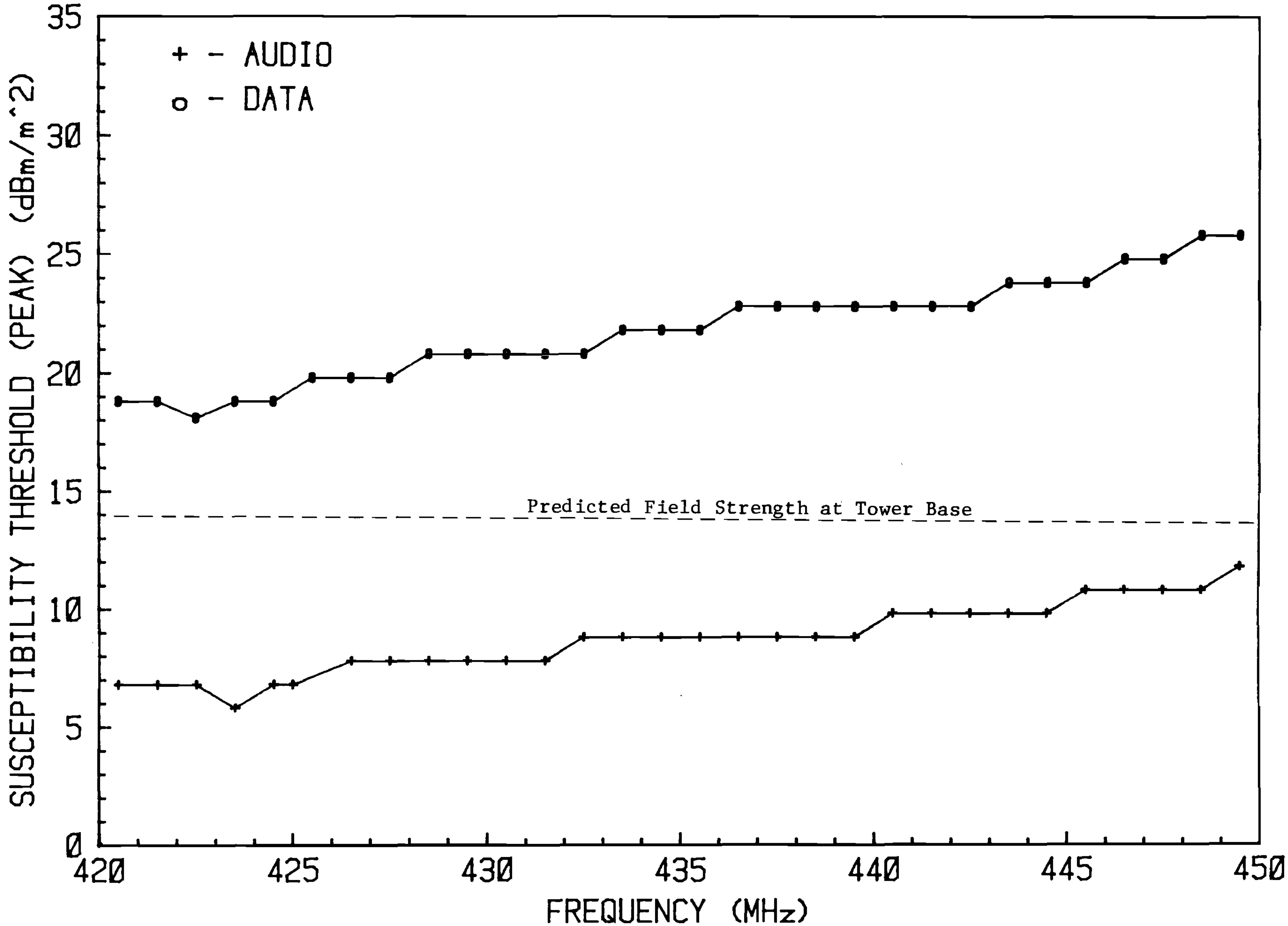


Figure 1. Susceptibility Threshold Versus Frequency for Receiver/Multiplexer Radiated Channel G1 (4 - 8 kHz).

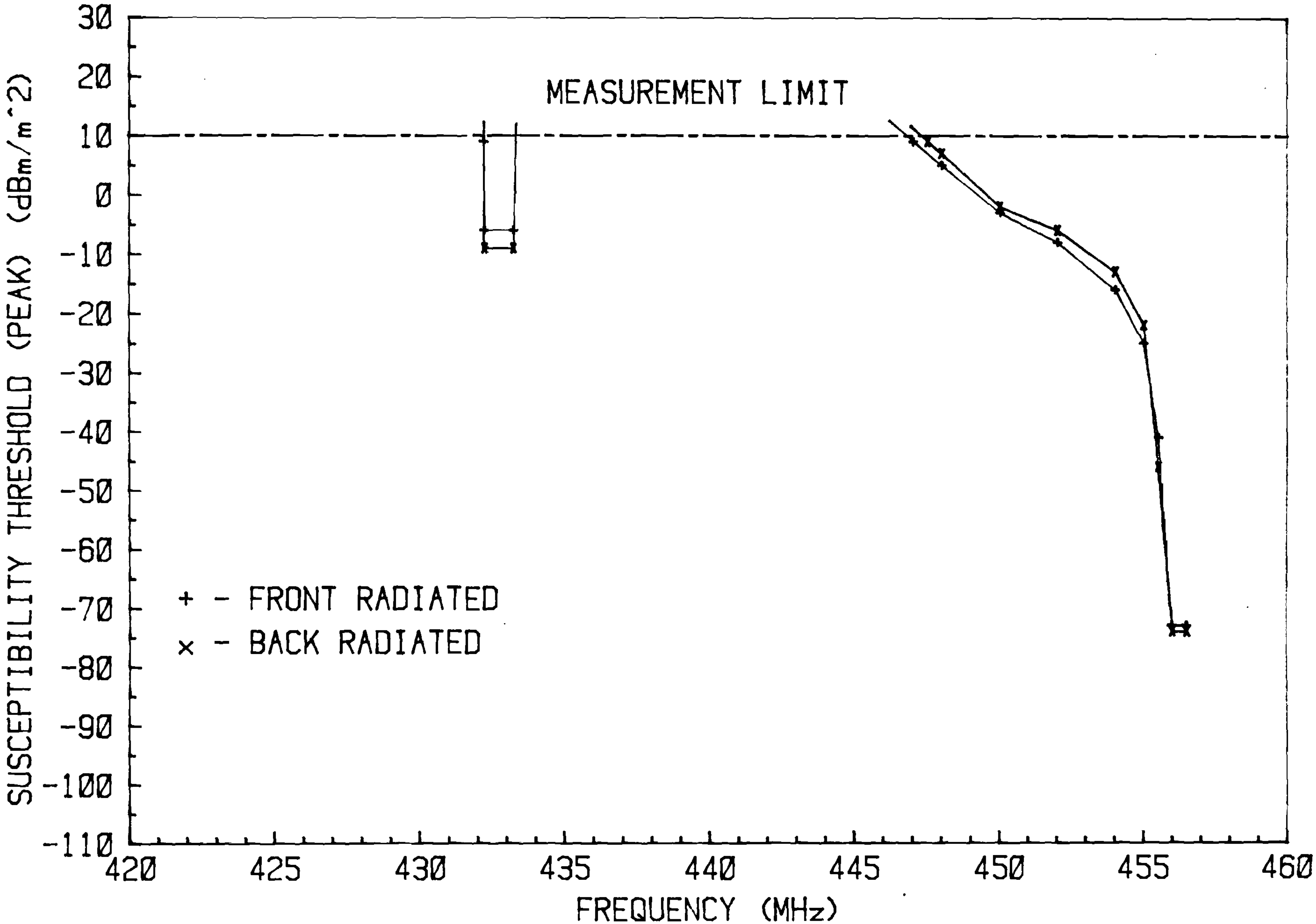


Figure 2. Open-System Interference Susceptibility Threshold Versus Frequency for Repeater with No Antenna.

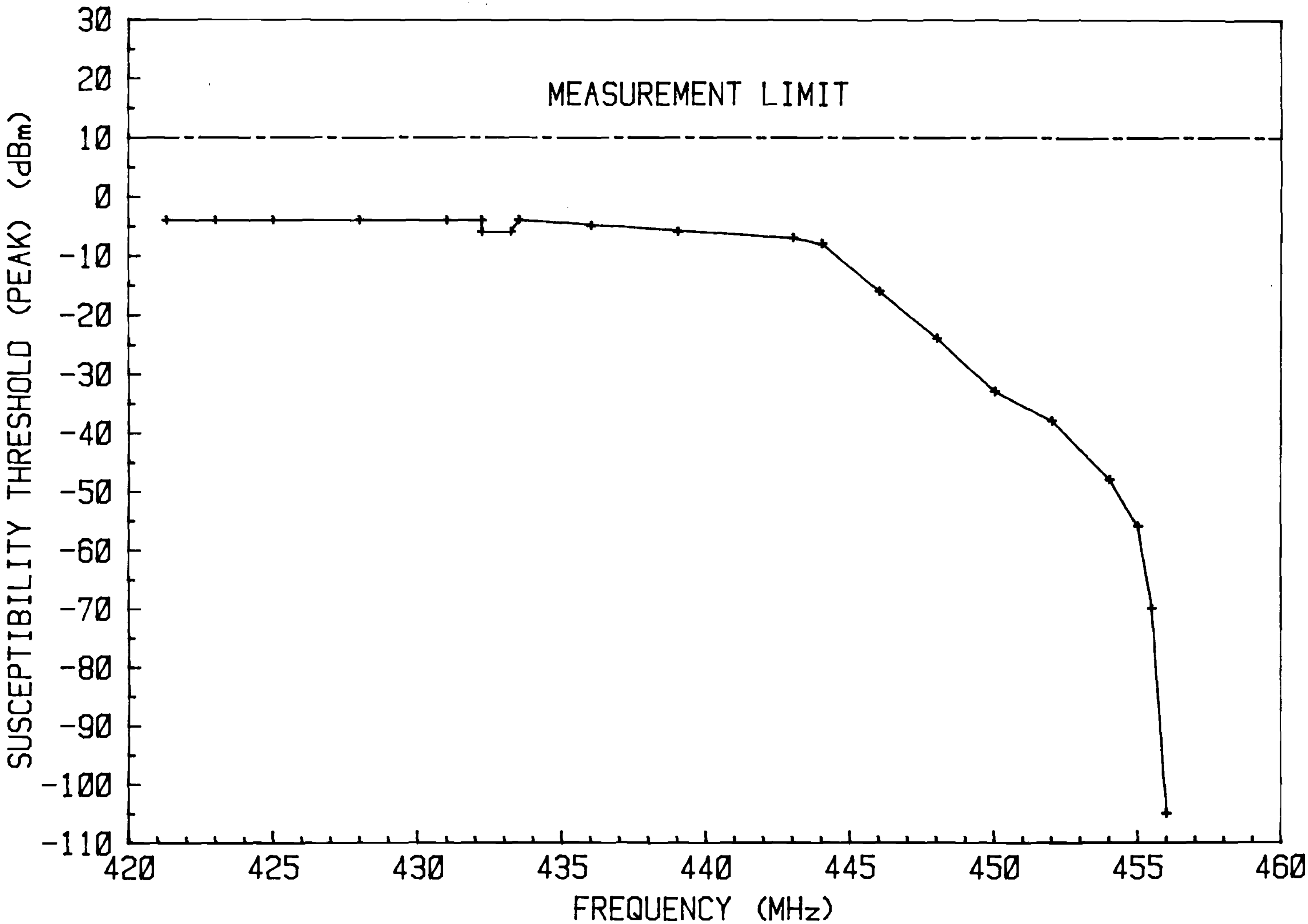


Figure 3. Closed-System Interference Susceptibility Threshold Versus Frequency for Repeater.

Georgia Institute of Technology
ENGINEERING EXPERIMENT STATION
Atlanta, Georgia 30332

16 December 1983

Georgia Power Company
107 Technology Park
Norcross, GA 30092

Attention: J. E. Thomas

Subject: Progress Report No. 6, Project A-3597
Report Period: 30 November 1983 to 31 December 1983
P. O. No. K-50024, "PAVE PAWS Interference Study."

Gentlemen:

The subject program was initiated on 8 July 1983. The overall objective of this program is to identify the potential for interference to Georgia Power communication systems from the "PAVE PAWS" radar system to be installed at Robins Air Force Base (Warner Robins, Georgia). The PAVE PAWS radar is a large phased array radar system which operates at very high RF power levels in the 420 to 450 MHz frequency range. Since the Georgia Power Company operates both a 450 MHz mobile radio network and a 6 GHz microwave link in the immediate vicinity of the proposed radar installation site, the potential exists for the radar system to cause interference to components of these two communications systems. The identification of potential interference problems is necessary to permit the Georgia Power company to take appropriate corrective actions prior to the installation of the PAVE PAWS system (the 1985-86 time frame).

To accomplish the above objective, program efforts will be directed to five major tasks:

(1) Evaluate available information to identify the operating characteristics and interference potential of the PAVE PAWS radar system.

(2) Perform interference susceptibility measurements on selected components of the 450 MHz mobile radio network.

(3) Perform interference susceptibility measurements on selected components of the 6 GHz microwave link.

(4) Perform analyses and computer simulations to predict the radar field intensity levels to which communication system components will be exposed and to assess the effects of these levels on the performance of the 450 MHz and 6 GHz communication systems.

(5) Document the results of the analytical investigations and experimental measurements along with conclusions and recommendations concerning the potential effects of PAVE PAWS on the two communications systems.

During this reporting period, assessments of potential interference problems (Task 4) were continued. Also, the preparation of draft material for the program report was initiated.

A presentation of program activities and results to date was given to Georgia Power Company personnel on 6 December 1983. A brief summary of the major results and conclusions which were presented at this meeting is given below. It is important to recognize that the conclusions are <u>preliminary</u> in that Task 4 has not yet been completed. The analysis results must be modified to reflect (1) a more detailed characterization of test specimen susceptibility data, (2) likely differences in the "actual" PAVE PAWS spectrum and the spectrum of the simulated PAVE PAWS signal used in the susceptibility measurements, and (3) the finalization of parameters used in the prediction of field strength levels. Not withstanding these three constraints, the results to date are sufficiently accurate to identify the probable existence, if not the extent, of potential interference problems.

Preliminary interference assessments were performed by comparing the measured (worst-case) susceptibility thresholds of the test specimen UHF and microwave receivers to predicted field strenth levels. The results of these assessments are illustrated in Figures 1 through 4. Figure 1 compares the predicted field strength level (13.7 dBm/m^2) at the base of the tower to the audio and data susceptibility thresholds of the microwave receiver/multiplexer. Note from this figure that the predicted field strength is approximately 8 dBm/m^2 above the audio threshold (interference likely), but 4 dBm/m^2 below the data threshold (interference unlikely). Note that these assessments do not include the effects of pulse width and pulse repetition frequency, which are likely to lower the susceptibility thresholds of the microwave receiver/multiplexer. The final analyses may indicate field strength levels which are above both the audio and data thresholds.

Figures 2 and 3 show preliminary assessments of interference to the UHF repeater. Figure 2 illustrates the potential for case radiated interference, whereas Figure 3 shows the potential for antenna conducted interference. Note from Figure 2 that the predicted field strength at the bottom of the repeater tower is roughly 14 dB above the case-radiated susceptibility threshold of the repeater. Although this difference is a definite indication of potential interference problems, such problems could possibly be resolved through better shielding of the receiver case or housing structure. However, Figure 3 shows that severe interference may be experienced due to antenna coupled interference signals. Note that the predicted interference signal level at the repeater antenna terminals is roughly 72 dB above the repeater susceptibility threshold. It is expected that extensive measures will be necessary to alleviate antenna coupled interference problems.

Since the mobile UHF receivers will not operate at a fixed distance or location relative to the PAVE PAWS radar site, preliminary interference assessments were performed by calculating the distances from the radar at which predicted field strength levels were equal to the measured susceptibility thresholds. These distance calculations are illustrated graphically in Figure 4. Note from this figure that predicted field strength levels are larger than measured receiver susceptibility thresholds over a large geographical area surrounding the radar site. For mobile receivers operating within the main beam scan angle of the radar, distances of approximately 50 miles will be necessary for the receivers to operate "interference-free."

From the above preliminary results, the following tentative conclusions can be drawn:

(1) Interference to mobile UHF equipment is highly probable within a relatively large area surrounding the PAVE PAWS site.

(2) Severe interference to the UHF repeater is highly probable via antenna conducted interference.

(3) Interference to the microwave receiver is probable but should be resolvable through appropriate corrective actions.

The following tasks are still to be accomplished under the program:

(1) Identify the "actual" PAVE PAWS spectrum.

(2) Modify or interference assessments based on "new" spectrum characteristics.

(3) Continue/finalize interference assessments.

(4) Identify possible approaches to alleviate interference problems.

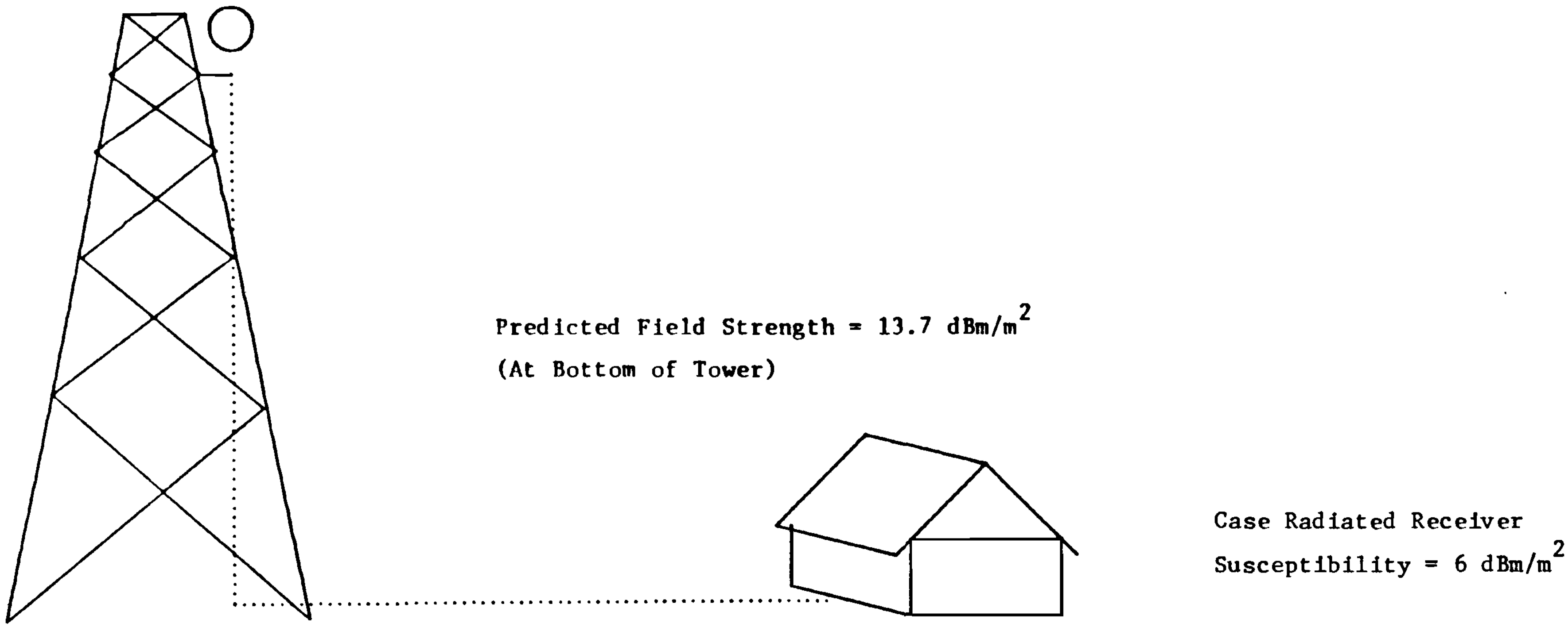
(5) Document the program results in a report to Georgia Power.

Respectfully submitted,

Ernest E. Donaldson
Project Director

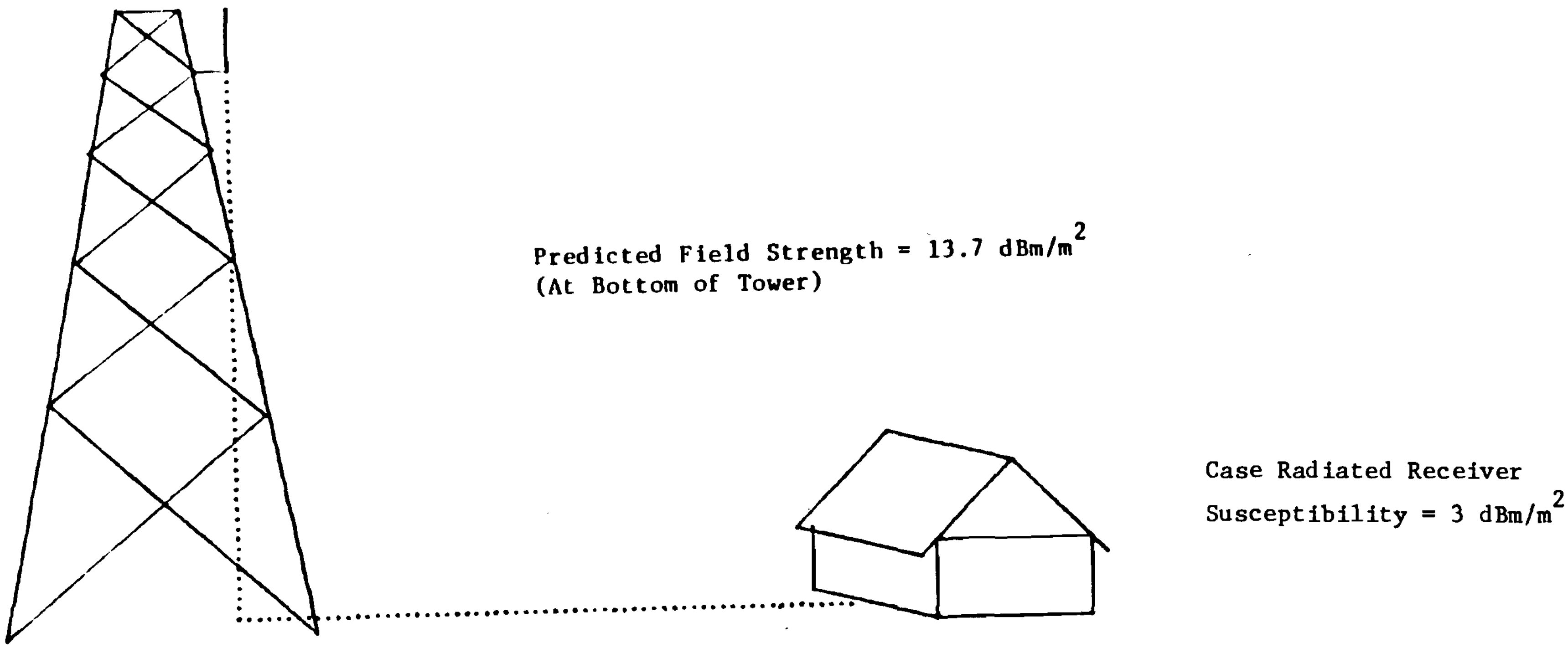
Approved:

H. W. Denny, Chief
Electromagnetic Compatibility Division



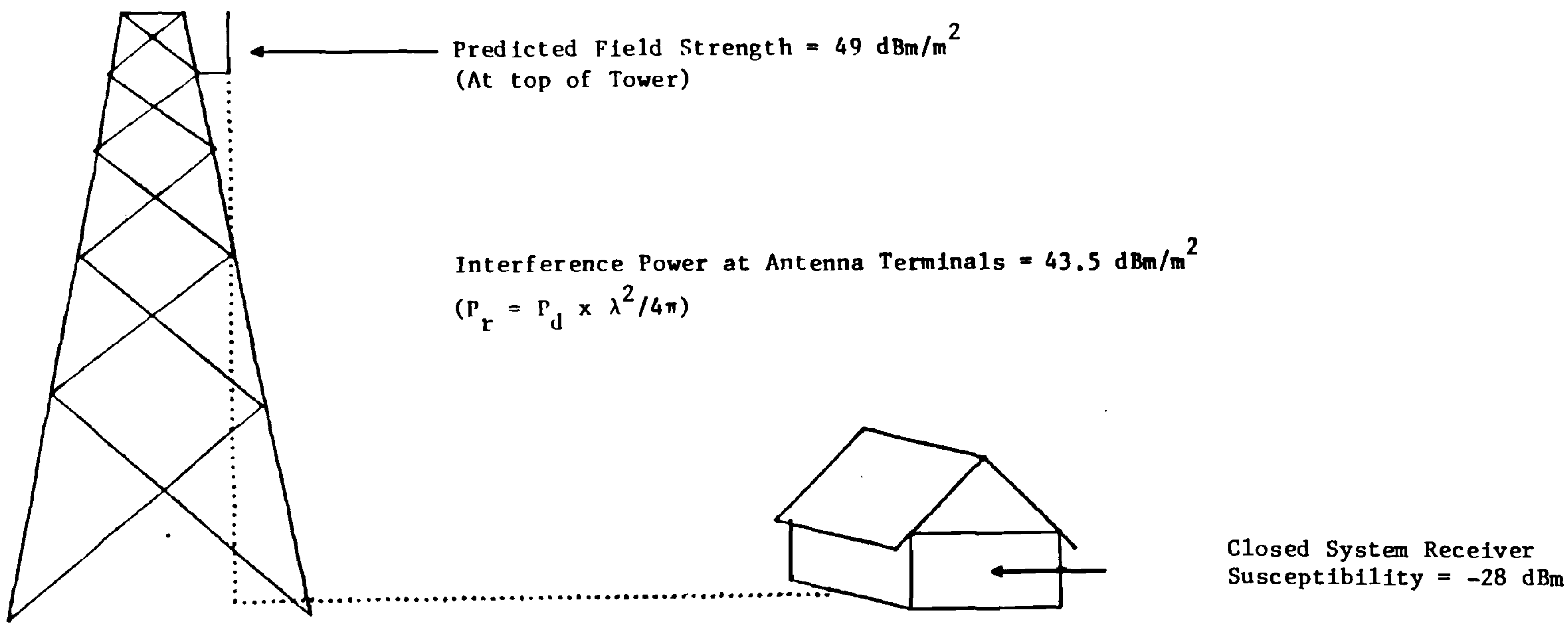
Field Strength Level is 7.7 dB Above Audio Susceptibility.
Threshold Level is 4.3 dB Below Data Threshold Level.

Figure 1. Preliminary Interference Assessment for Microwave Receiver/Multiplexer.



Field Strength Level is 10.7 dBm/m^2 Above Susceptibility Threshold Level

Figure 2. Preliminary Interference Assessment for UHF Repeater-Case Radiated Interference.



Interference Power Level is 71.5 dB Above
Susceptibility Threshold Level.

Figure 3. Preliminary Interference Assessment for UHF Repeater-Antenna Conducted Interference.

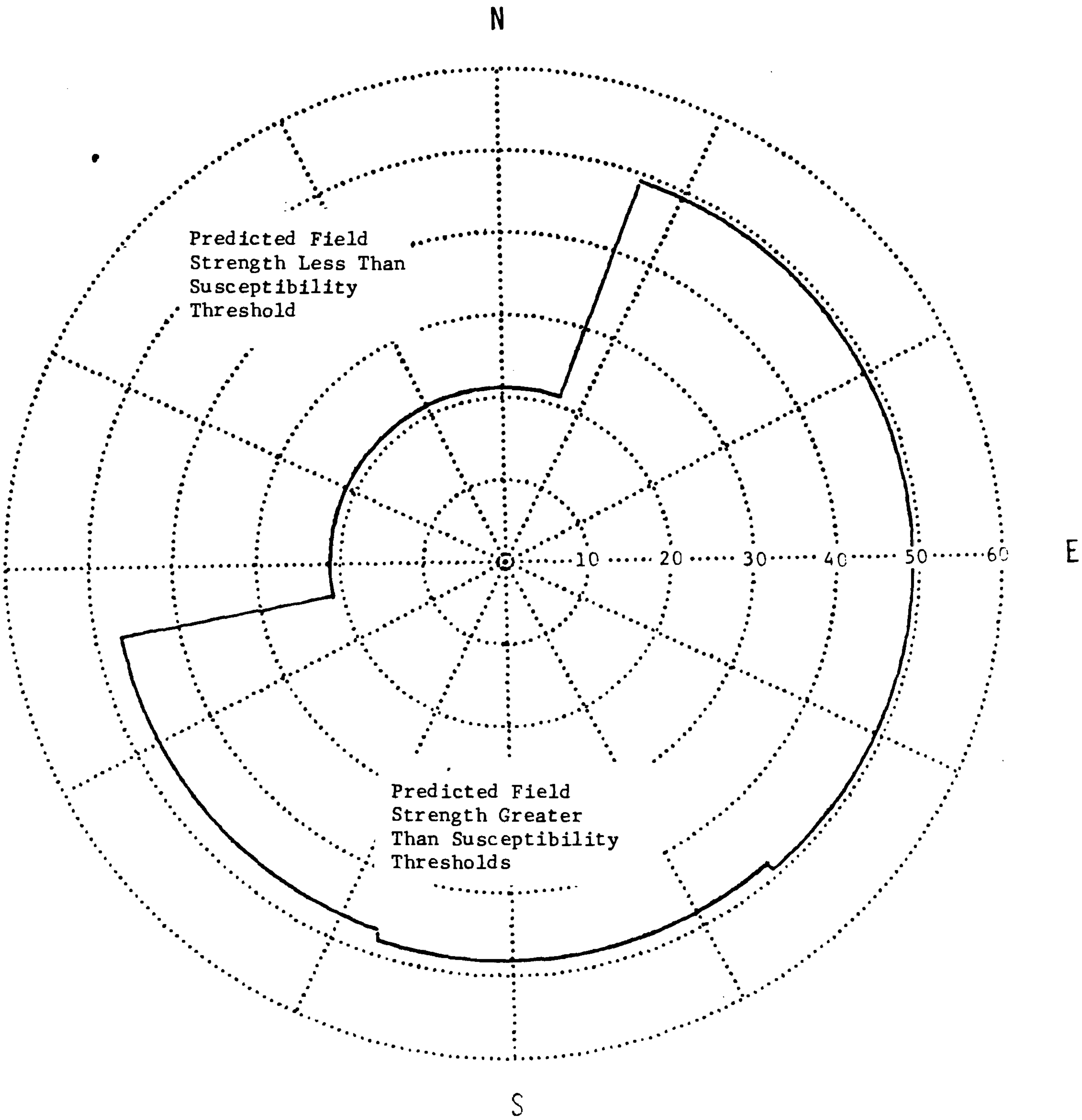


Figure 4. Preliminary Interference Assessment for UHF Mobile Receivers.

Georgia Institute of Technology
ENGINEERING EXPERIMENT STATION
Atlanta, Georgia 30332

23 January 1983

Georgia Power Company
107 Technology Park
Norcross, GA 30092

Attention: J. E. Thomas

Subject: Progress Report No. 7, Project A-3597
Report Period: 30 November 1983 to 31 December 1983
P. O. No. K-50024, "PAVE PAWS Interference Study."

Gentlemen:

The subject program was initiated on 8 July 1983. The overall objective of this program is to identify the potential for interference to Georgia Power communication systems from the "PAVE PAWS" radar system to be installed at Robins Air Force Base (Warner Robins, Georgia). The PAVE PAWS radar is a large phased array radar system which operates at very high RF power levels in the 420 to 450 MHz frequency range. Since the Georgia Power Company operates both a 450 MHz mobile radio network and a 6 GHz microwave link in the immediate vicinity of the proposed radar installation site, the potential exists for the radar system to cause interference to components of these two communications systems. The identification of potential interference problems is necessary to permit the Georgia Power company to take appropriate corrective actions prior to the installation of the PAVE PAWS system (the 1985-86 time frame).

To accomplish the above objective, program efforts will be directed to five major tasks:

(1) Evaluate available information to identify the operating characteristics and interference potential of the PAVE PAWS radar system.

(2) Perform interference susceptibility measurements on selected components of the 450 MHz mobile radio network.

(3) Perform interference susceptibility measurements on selected components of the 6 GHz microwave link.

(4) Perform analyses and computer simulations to predict the radar field intensity levels to which communication system components will be exposed and to assess the effects of these levels on the performance of the 450 MHz and 6 GHz communication systems.

(5) Document the results of the analytical investigations and experimental measurements along with conclusions and recommendations concerning the potential effects of PAVE PAWS on the two communications systems.

During this reporting period, technical efforts under the program were essentially completed, and the program technical report was initiated. Table I shows a tentative outline which has been prepared to guide the preparation of material for the report. Note that the material following the report introduction will be divided into four major topical areas. Section 2, Interference Susceptibility Measurements, will describe the measurements performed to identify the susceptibility of the test specimen UHF and microwave receivers--what was measured, how it was measured, and the results obtained.

Section 3, Electromagnetic Environment created by PAVEPAWS, will summarize the general operating characteristics of PAVEPAWS, and present predictions of field strength based on these characteristics and the terrain characteristics in the vicinity of Robins Air Force Base. Field strength predictions using both a statistical area model and a point-to-point model will be described.

Section 4, Interference Assessments, will provide assessments of potential interference to the UHF mobile, UHF repeater, and microwave receivers. For the UHF mobile receivers, the assessments will be based on both the output of the statistical area model and prediction data provided by the Electromagnetic Compatibility Analysis Center (ECAC). The point-to-point field strength predictions will be used to assess potential problems to the UHF repeater and microwave receiver (at both ground level and top of tower).

Section 5, Conclusions and Recommendations, will summarize the nature and extent of potential problems, and recommend possible actions which may be taken to mitigate identified interference problems.

To date, draft material for the final report has been prepared for Sections 1, 2, and 3, and work on Section 4 and 5 is currently underway. Efforts to complete the report will continue during the next reporting period.

Respectfully submitted,

Ernest E. Donaldson
Project Director

Approved:

H. W. Denny, Chief
Electromagnetic Compatibility Division

TABLE I

3.3 PAVE PAWS Field Strength Predictions
- 3.3.1 General
- 3.3.2 Topographic Considerations
- 3.3.3 Statistical Area Model
- 3.3.4 Point-to-Point Model
- 3.3.5 Field Strength Data

4. INTERFERENCE ASSESSMENTS
- 4.1 General
- 4.2 UHF Land Mobile Equipment
- 4.3 UHF Repeater
- 4.4 Microwave System

5. CONCLUSIONS AND RECOMMENDATIONS

APPENDICES AS NECESSARY

Georgia Institute of Technology
ENGINEERING EXPERIMENT STATION
Atlanta, Georgia 30332

23 February 1984

Georgia Power Company
107 Technology Park
Norcross, GA 30092

Attention: J. E. Thomas

Subject: Progress Report No. 8, Project A-3597
Report Period: 31 January 1984 to 29 February 1984
P. O. No. K-50024, "PAVE PAWS Interference Study."

Gentlemen:

The subject program was initiated on 8 July 1983. The overall objective of this program is to identify the potential for interference to Georgia Power communication systems from the "PAVE PAWS" radar system to be installed at Robins Air Force Base (Warner Robins, Georgia). The PAVE PAWS radar is a large phased array radar system which operates at very high RF power levels in the 420 to 450 MHz frequency range. Since the Georgia Power Company operates both a 450 MHz mobile radio network and a 6 GHz microwave link in the immediate vicinity of the proposed radar installation site, the potential exists for the radar system to cause interference to components of these two communications systems. The identification of potential interference problems is necessary to permit the Georgia Power company to take appropriate corrective actions prior to the installation of the PAVE PAWS system (the 1985-86 time frame).

To accomplish the above objective, program efforts will be directed to five major tasks:

(1) Evaluate available information to identify the operating characteristics and interference potential of the PAVE PAWS radar system.

(2) Perform interference susceptibility measurements on selected components of the 450 MHz mobile radio network.

(3) Perform interference susceptibility measurements on selected components of the 6 GHz microwave link.

(4) Perform analyses and computer simulations to predict the radar field intensity levels to which communication system components will be exposed and to assess the effects of these levels on the performance of the 450 MHz and 6 GHz communication systems.

(5) Document the results of the analytical investigations and experimental measurements along with conclusions and recommendations concerning the potential effects of PAVE PAWS on the two communications systems.

During this reporting period, the draft version of the program technical report was completed. The report is now undergoing final review and editing. It is anticipated that the final version of the report will be completed and ready for submission within the next few days.

Respectfully submitted,

Ernest E. Donaldson
Project Director

Approved:

H. W. Denny, Chief
Electromagnetic Compatibility Division

A-3597

FINAL TECHNICAL REPORT
GT/EES PROJECT A-3597

PAVE PAWS INTERFERENCE STUDY

By

E. E. Donaldson, B. M. Jenkins, D. W. Acree
T. G. Shands, E. A. Nelson, and J. P. Garmon

Prepared for

GEORGIA POWER COMPANY
107 Technology Park
Norcross, Georgia 30092

Under

Purchase Order No. K-50024

March 1984

GEORGIA INSTITUTE OF TECHNOLOGY
A Unit of the University System of Georgia
Engineering Experiment Station
Atlanta, Georgia 30332

1984

Final Report

March 1984

PAVE PAWS INTERFERENCE STUDY

Prepared by

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For

Georgia Power Company
107 Technology Park
Norcross, Georgia

FOREWORD

This report was prepared by the Georgia Tech Engineering Experiment Station under Georgia Power Purchase Order NO. K-50024, Georgia Tech Project No. A-3597. The work described in the report was directed by Mr. E. E. Donaldson, Project Director, under the general supervision of Mr. H. W. Denny, Chief of the Electromagnetic Compatibility Division.

ABSTRACT

This report presents the results of investigations performed to identify the potential for interference to Georgia Power Company communication systems from the PAVE PAWS radar at Robins Air Force Base. These investigations involved: (1) interference susceptibility measurements on selected test specimen communication receivers and equipment; (2) analytical predictions of the electromagnetic environment which will be produced by PAVE PAWS; (3) the assessment of potential interference problems through comparisons of predicted environmental levels with measured receiver susceptibility characteristics, and (4) the identification of possible methods of mitigating identified problems.

The interference susceptibility measurements were performed on UHF and microwave communication equipment supplied by the Georgia Power Company. These equipment included UHF land mobile receivers (SYNTOR, MICOR, Base Station, and Handi-Talkies), a UHF repeater receiver, and a microwave receiver and multiplexer. Both radiated and antenna conducted susceptibility characteristics of the equipment were measured, as appropriate, using a simulated PAVE PAWS signal. A worst-case test philosophy was employed which tended to maximize the susceptibility of the equipment to interference. This philosophy was used to provide a "margin of safety" in defining and resolving potential interference problems.

The results of the interference susceptibility measurements performed on the test specimen UHF and microwave system components can be summarized as follows:

(1) The worst-case radiated susceptibility threshold measured on the mobile UHF receivers (SYNTOR, MICRO, Base Station, and Handi-Talkies) was approximately -39 dBm/m^2.

(2) For the UHF repeater, the worst-case case-radiated susceptibility threshold measured was approximately -9 dBm/m^2. The worst-case antenna-conducted susceptibility threshold was -30 dBm.

(3) The worst-case audio susceptibility threshold recorded on the microwave receiver was +15 dBm/m^2. For the receiver alone test configuration, no interference to the data signal was noted.

(4) For the microwave receiver/multiplexer test configuration, the worst-case audio threshold which was measured was -4 dBm/m^2. The worst-case data threshold was +8 dBm/m^2.

Analytical predictions of the electromagnetic environment created by PAVE PAWS was performed using computer-based prediction models. A point-to-point prediction model was used to predict the field strength of the PAVE PAWS signal at the UHF repeater/microwave receiver tower site. An area prediction model was used to predict field strengths for interference assessments of UHF mobile receivers. The predictions yielded the following results:

(1) At the top of the tower on which the UHF repeater antenna is located, the predicted field strength level is +49 dBm/m^2.

(2) At the building which houses the UHF repeater receiver and microwave system components, the predicted field strength is +14 dBm/m^2.

(3) For the mobile UHF receivers, the distance from the PAVE PAWS site at which the predicted field strength is equal to the worst-case susceptibility threshold is approximately 73 kilometers.

By comparing the measured susceptibility data and the predicted field strength levels, the following interference assessments can be made:

(1) The interference signal power at the UHF repeater antenna terminals due to pickup via the repeater antenna will be approximately 74 dB above the worst-case antenna-conducted susceptibility threshold of the repeater receiver. This large difference between the interference power level and the receiver susceptibility threshold indicates a severe interference problem.

(2) The field strength at the UHF repeater receiver location is 23 dB above the worst-case case-radiated susceptibility threshold of the receiver. Thus even without consideration of antenna conducted interference problems, the repeater receiver will likely suffer interference problems from case-radiated signals.

(3) For the microwave receiver and multiplexer, the predicted field strength is 18 dB and 6 dB, respectively, above the worst-case audio and data thresholds. Case-radiated interference problems are thus likely to occur.

(4) Interference to the UHF mobile receivers is likely to occur if the receivers are operated within a radius of 73 kilometers of the radar site.

Several methods for mitigating interference effects in the UHF and microwave systems were identified. These methods involve changes in the location and height of the repeater tower, changes in the operating frequencies of the UHF land mobile network, pattern control of the UHF repeater antenna, shielding, filtering, etc. The proper application of the methods should substantially reduce interference effects in the UHF repeater and microwave receiver/multiplexer. Interference to the UHF land mobile receivers will be more difficult to resolve because of their mobility requirements and because their compact design configuration inhibits the application of interference suppression techniques and devices.

Several issues must be addressed prior to selecting any mitigation method or combination of methods. Criteria for what constitutes "acceptable" interference must be established, the technical characteristics, merits, and limitations of the various mitigation methods must be defined, possible tradeoffs or conflicts between mitigation methods and system operational requirements must be resolved, and cost factors must be identified.

TABLE OF CONTENTS

LIST OF FIGURES

PAGE

PAGE

LIST OF TABLES

1.0 INTRODUCTION

1.1 Statement of Problem

The U.S. Air Force is planning to install a PAVE PAWS radar system at Robins Air Force Base, Warner Robins, Georgia, in the 1985-1986 time frame. The PAVE PAWS radar is a large phased array radar system which operates at very high RF power levels in the 420 to 450 MHz frequency range. Since the Georgia Power Company operates both a UHF (450 - 460 MHz) mobile radio network and a microwave (6.5 GHz) communications link in the immediate vicinity of the planned radar installation site, the potential exists for the radar system to cause interference to components of these two systems. The identification of potential interference problems is necessary to permit the Georgia Power Company to take appropriate corrective actions prior to the installation of the PAVE PAWS system.

1.2 Program Objectives and Scope

The primary objective of the research program conducted under Purchase Order No. K-50024, "PAVE PAWS Interference Study," was to identify the potential for interference to Georgia Power Company communications systems from the PAVE PAWS radar system at Robins Air Force Base. A secondary objective was to develop a base of information and data which will aid Georgia Power in the identification of any actions necessary to mitigate potential interference problems.

Three major tasks were undertaken to satisfy the program objectives. Under the first task, interference susceptibility measurements were performed on selected components of the Georgia Power UHF mobile radio and microwave systems. The purpose of these measurements was to characterize the susceptibility of the communication system components to simulated PAVE PAWS emissions.

The second task involved analytical predictions of the electromagnetic environment which will be produced by the PAVE PAWS radar. These predictions provide a definition of the field strength levels to which components of the Georgia Power communication systems will likely be exposed.

The third and final task was to assess the potential for interference to the UHF and microwave systems through comparisons of the equipment susceptibility characteristics measured under Task 1 with the predicted field strength levels of Task 2. In these comparisons, potential interference problems could be identified for those cases where predicted field strength levels exceeded the measured interference threshold levels. The comparisons also provided a means of defining possible approaches to resolving identified problems.

1.3 Report Organization

The material which follows in this report is divided into four major sections (Section 2 through 5) and three appendices. Section 2 describes the measurement program which was undertaken to identify the interference susceptibility characteristics of selected components of the Georgia Power Company UHF and microwave systems. Section 3 describes computer-based calculations which were performed to predict the electromagnetic environment which will be created by emissions from the PAVE PAWS system at Robins Air Force Base, and Section 4 identifies the potential effect of this environment on the performance of the Georgia Power UHF and microwave communication systems. Section 5 identifies possible actions which may be taken to preclude or minimize PAVE PAWS related interference effects, Section 6 presents the program conclusions and recommendations, and Section 7 lists the reference material used in the program.

2.0 INTERFERENCE SUSCEPTIBILITY MEASUREMENTS

2.1 General

When exposed to a given radiated electromagnetic environment, an electronic equipment may experience a degradation in performance (i.e., may be susceptible to undesired effects from the environment) depending upon (1) the level and characteristics of the energy coupled from the environment to the equipment, and (2) the response of the equipment circuitry to the coupled energy. Except for very simple cases, the susceptibility of an equipment is difficult to define by theoretical means because of the multitude of coupling paths/path losses which may exist and because of the complexity of circuit responses to undesired signals. For example, an environmental signal may be coupled to circuitry internal to an equipment via direct case penetration, through antenna, power, and signal cables, or by a combination of these routes. The effects of coupled energy on the performance of equipment circuitry will depend upon such factors as circuit function (power, sensing, etc.), circuit type (analog vs. digital), circuit components (vacuum-tube, solid-state), circuit frequency and bandwidth characteristics, etc. For these reasons, the susceptibility characteristics of equipment are usually determined by experimental measurements rather than by analysis.

Under this study, a measurement program was developed to define the susceptibility characteristics of Georgia Power UHF and microwave communications equipment when subjected to simulated PAVE PAWS radar signals. The following paragraphs identify the test specimen communication equipment, the test approach and test configurations which were employed, and the susceptibility data which were recorded.

2.2 Test Specimen Equipment

Susceptibility measurements were performed on the UHF and microwave equipment listed in Table I. These equipment, which were selected and supplied by the Georgia Power Company, obviously represent only a limited sample of the equipment employed in the Georgia Power UHF and microwave

TABLE I

TEST SPECIMEN EQUIPMENT

UHF EQUIPMENT

Motorola Model T64SRA3JOOK SYNTOR FM Two-Way Radio, Serial No. 431HEL0248

Motorola Model T74RTA1803BASP05 MICOR FM Two-Way Radio, Serial No. S6107U

Motorola Model L44BCB-3190BM Base Station, Serial No. MA2679

Motorola Model R-3120 FM Repeater, Serial No. 308-5531

38-1/2 inch UHF Monopole Antenna

6-1/4 inch UHF Monopole Antenna

Motorola HT220 Handi-Talkie FM Radio, Serial No. P42D44

Motorola MT500 Handi-Talkie FM Radio, Serial No. 511AC00079

MICROWAVE EQUIPMENT

Collins Microwave Receiver

Granger Associates DTL 7300 MULTIPLEX Unit, Serial No. 314034 communications networks. However, the susceptibility data recorded on these test specimens should be sufficient to approximate the nature and extent of interference problems likely to be caused by the PAVE PAWS radar system.

2.3 Test Approach

2.3.1 Test Environment

With the exception of some exploratory measurements, the susceptibility tests were performed in an anechoic chamber in order to simulate open-field conditions and to isolate the test environment from extraneous signals. The anechoic chamber used for the tests provides an inside working volume which is approximately 16 feet long, 12 feet wide, and 6 1/2 feet high. This chamber has a shielding effectiveness of greater than 100 dB, and the absorbing material lining the chamber walls, ceiling, and floor absorbs greater than 99 percent of the incident radiation over the frequency range from 300 MHz to 15 GHz.

A few exploratory measurements (e.g., measurements of receiver sensativity and selectivity) were performed in a closed system test configuration, with the test signals injected directly into the antenna terminals of the test specimen receivers. Since a radiated (open-system) environment was not required for these measurements, the measurements were performed in a shielded enclosure rather than the anechoic chamber. The shielded enclosure was used to isolate the test configuration from extraneous signals.

2.3.2 Philosophy

The susceptibility measurements were performed using test techniques, parameters, and procedures which tended to maximize the susceptibility of the test specimen equipment to interference, i.e., using a "worst-case" test philosophy. This philosophy was employed for three reasons. The first reason is that the test specimen equipment represents only a very small portion of the total equipment employed in Georgia Power communication systems. When measurements are performed on a limited sample of equipment to define the susceptibility of a large equipment population, the sufficiency of the sample size is always in question. A worst-case test philosophy thus provides a "margin of safety" in defining and resolving potential interference problems.

Second, measurements of equipment susceptibility to interference in a laboratory test environment cannot possibly duplicate the multiplicity of environmental conditions encountered in the field. Thus, worst-case type measurements also provide a margin of safety to account for possible variations between laboratory and field conditions.

A third reason involves the number of test variables or parameters which can influence the susceptibility of an electronic equipment to interference. For example, for tests performed under this program, typical test variables would include interference signal frequency, pulse width, repetition frequency, signal chirp width, receiver antenna type, desired signal characteristics (level and modulation), receiver volume control setting and squelch setting, etc. Even for this relatively small number of test variables, the number of possible combinations of these variables can reach a significant magnitude -- literally millions of individual tests would be required to accommodate all possible combinations. Thus, it would not be economically feasible to perform susceptibility measurements for each combination of variables. The worst-case measurement approach provides a means of obtaining realistic susceptiblity data while alleviating this particular measurement problem.

As an example of the application of the worst-case measurement concept, consider the effects of desired signal level on receiver susceptibility to interference (discussed further in Section 2.3.5). The results of measurements performed on the UHF test specimen receivers showed that their susceptibility to interference from the simulated PAVE PAWS signal increased (interference threshold decreased) as the desired signal input to the receiver decreased. Minimum interference thresholds occurred for a desired signal input near the receiver sensitivity level; i.e., near that level required to produce 20 dB of receiver quieting. This level of signal input was thus used for all UHF receiver tests in order to approximate worst-case susceptiblity thresholds, and no other measurements of susceptibility versus desired signal level were performed. Note that since this approach provides a pessimistic definition of receiver susceptibility, the resolution of interference problems based on the recorded test data will likely preclude problems at higher levels of desired signal input.

2.3.3 Interference Criteria

Measurements of the susceptibility of electronic equipment to interference requires that criteria be established for defining what constitutes a degradation in performance of the victim equipment. For the susceptibility tests performed on the Georgia Power UHF and microwave equipment, all measurements of interference effects were performed using a minimum detectible interference or threshold of interference criterion; i.e., that level of interference which just produces a perceptible change in equipment performance. Data interference thresholds (microwave equipment only) were measured quantitatively using a bit error rate detector. Audio interference thresholds were measured subjectively by listening to the audio output of the test specimen receivers.

The minimum detectible interference criterion was used for a number of reasons. One reason is that interference thresholds are relatively easy to identify and measure accurately. Even for audio signals, the subjective nature of audio interference measurements is not a significant factor when measuring interference thresholds, and untrained personnel can obtain consistent and repeatable results. On the other hand, once an interference threshold is exceeded, the specific effects and impact of an interference signal are difficult to define, being complexly related to the characteristics of the interference signal, the equipment design characteristics, and the functional relationship between equipment and system operating requirements. The identification and analysis of such effects would involve efforts considerably beyond the scope of the current program.

Another reason is that interference threshold measurements can be performed in a relatively straightforward manner. Test specimen equipment are simply subjected to a range of controlled and calibrated interference (field strength, voltage, etc.) conditions, and the level at which the minimum perceptible indication of interference occurs is recorded. Test personnel do not have to be concerned with any "degree" of interference or the manner in which interference affects the receiver; that level of interference signal which produces a detectable change in the performance of the receiver is the only measurement required.

Finally, the minimum detectable threshold criterion conforms to the worst-case test philosophy established for the susceptibility measurements. Actions taken to prevent interference problems identified from susceptibility data measured under this criterion will enhance the likelihood that all interference problems will be adequately resolved.

2.3.4 Interference Monitoring

Interference effects in the test specimen receivers were monitored by routing the receiver audio and data outputs to appropriate external monitoring devices. Audio signals were routed to a speaker or headset and to an RMS voltmeter. The voltmeter was used primarily as an aid in detecting the presence of interference pulses at low pulse repetition frequencies. Interference effects in data signals were monitored by routing the signal to a bit error rate detector.

2.3.5 Desired Signal Characteristics

The effects of interference on the performance of a communications receiver will depend upon the characteristics (level and modulation) of the desired signal (i.e., the signal the receiver is designed to receive). Prior to the initiation of tests, it was thus necessary to define the type of desired signal to be employed for susceptibility measurements on the UHF and microwave receivers. Once defined, the same desired signal characteristics were used throughout the test program.

For the test specimen UHF receivers, a CW signal was selected as the desired signal for all susceptibility measurements, for two reasons. One reason is that the use of a CW signal conforms to standard methods for conducting interference susceptibility tests on FM receivers. A second reason is that interference effects as measured at the receiver audio output are much easier to detect if the desired signal is unmodulated. In this respect, the use of a CW signal conforms to the worst case measurement philosophy.

The effects of desired signal level on the interference susceptibility of a receiver is largely dependent upon the type of interference which occurs. For frequency dependent interference cases (co-channel interference, spurious responses, intermodulation), where the interfering signal is routed through the IF amplifier stages along with the desired signal, the interference susceptibility threshold of the receiver is usually highly dependent upon the desired signal level, due to automatic gain control (AGC) action in the receiver amplifier stages. For large desired signal input levels, the gain of the amplifier stages is minimized, thus reducing their response to the interference signal. Conversely, if a low level signal is received, the gain is increased, thus "improving" the receiver response to interference.

For non-frequency dependent (high power effects) cases of interference, where the interference signal is not routed via the normal receiver signal path (mixer, IF amplifiers, etc), the mechanisms by which interference is produced and the effects of the desired signal level on the receiver interference threshold are ill defined. Changes in the desired signal level do not necessarily produce a predictable change in the interference threshold; i.e., increasing the desired signal level may cause an increase or decrease in this threshold. However, it can be generally stated that the effects of the desired signal level on the interference threshold of a receiver are much less pronounced for non-frequency dependent cases of interference than for cases where the interfering signal is within the receiver passband.

Because of the spectral characteristics of the PAVE PAWS signal, and because the PAVE PAWS frequency band is close to the operating frequencies of the UHF receivers, it could be reasonably judged that (1) the predominant interference effects in the UHF receivers would be caused by frequency dependent interference (i.e., by co-channel interference or by spurious responses), and (2) that the desired signal level employed in the susceptibility measurements would influence receiver susceptibility to interference. For these reasons, preliminary measurements were performed to establish the level of desired signal to be used for susceptibility measurements on the set of test specimen UHF receivers.

For the microwave receiver, test equipment provided by the Georgia Power Company were used to configure the receiver for susceptibility tests. These equipment provided standard desired signals typically employed for the operation, checkout and maintenance of the receiver and multiplexer. For this reason, the investigation and selection of desired signal characteristics for the microwave receiver susceptibility tests were not required. All tests were performed using the standard test signal.

Since the operating frequency of the microwave receiver is far removed from the PAVE PAWS frequency band, it is likely that the predominant cause of interference to the microwave receiver will be due to high power effects. Because the effects of desired signal level on high power type interference thresholds are difficult to predict, measurements of interference thresholds versus desired signal level were performed for each of the five receiver channels tested.

2.3.6 Test Specimen Controls and Adjustments

All test specimen equipment supplied by the Georgia Power Company was tested in an "as received" condition; i.e., no special adjustments or check-outs were performed. With one exception, all of the equipment appeared to be in good operating order, with nominal operating characteristics (e.g., sensitivity, selectivity, etc.) which conformed to the values specified in the operating manuals. The exception was the receiver in the UHF repeater unit, which appeared to be slightly mistuned. However, subsequent adjustments of the receiver by Georgia Power personnel did not significantly affect its measured susceptibility characteristics.

The primary controls which required setting for the susceptibility measurements were the SQUELCH and VOLUME controls on the UHF receivers. Except for exploratory measurements where the effects of SQUELCH were investigated, all measurements were performed with the receiver SQUELCH turned off in order to maximize the detection of undesired interference effects.

The VOLUME control on the test specimen receivers was set by first injecting a desired signal level which provided 20 dB of receiver quieting. The input signal was then modulated with a 1000 HZ tone at 1.5 kHz deviation, and the VOLUME control was adjusted to provide an audio output of 0.53 volts RMS. The 1000 Hz modulation was removed prior to beginning susceptibility measurements.

The 0.53 volt audio output setting was somewhat arbitrary in that once the receiver volume is increased to the point where interference is detectable, changes in the VOLUME setting will not significantly affect interference threshold levels. This particular VOLUME setting was selected based on judgements of the normal settings likely to be used under typical receiver operating conditions. Once selected, this same method of setting the VOLUME control was used for all of the UHF test specimen receivers.

The UHF repeater and microwave receiver did not have external or easily accessible volume controls. For these receivers, audio amplifiers were employed to adjust the audio output to 0.53 volts. This approach was considered desirable in order to establish a consistent method of test for all receivers.

2.3.7 Test Specimen Orientation

The orientation of a receiver with respect to an interference source will influence its susceptibility to interference depending upon the mode of interference signal coupling. If signal pickup is primarily through the receiver antenna, then the orientation of the receiver case will have little effect on receiver susceptibility. On the other hand, if signal coupling is via the receiver case, the orientation of the case may significantly impact the susceptibility of the receiver to interference. Depending upon such factors as the polarization characteristics of the interference signal and the physical configuration of the victim equipment (case structure, component and circuit layout, location of susceptible circuits, etc.), interference which is severe at one orientation may be insignificant at another. Since commercial communication receivers are not necessarily well shielded, case penetration by interference signals is likely to occur. Thus, measurements of receiver interference susceptibility thresholds must include the effects of receiver orientation.

Ideally, measurements of receiver susceptibility versus case orientation should include all orientations of the receiver with respect to the interference source. In practice, such an approach is obviously not feasible since it would require an infinite number of measurements.

The orientations selected for measurements on the UHF receivers depended upon the physical characteristics of the receivers, the measurment configurations required, and judgements as to the orientations likely to be most susceptible to the PAVE PAWS signal. For the susceptibility measurements performed on the test specimen UHF mobile and base station receivers, measurements were made with each of the four sides of the receiver case oriented in the direction of the interference source antenna. The UHF repeater was configured in a rack with a relatively heavy frame such that wiring, cabling, and circuitry were exposed primarily on two sides -- the front and back. For this reason, the susceptibility measurements on the repeater were performed only at two orientations, one with the front of the repeater exposed to the interference source antenna and the other with the back exposed. Measurements on the Handi-Talkies required the use of a microphone positioned next to the Handi-Talkie in order to monitor the audio signal. Because this configuration made it difficult to rotate the test specimen, only the left side of the Handi-Talkie was exposed to the antenna (the front of the Handi-Talkie was defined as that face containing the speaker).

The microwave receiver and multiplexer were tested at only one orientation, since the size and weight of the receiver rack limited the number of orientations that could be accomodated in the anechoic chamber. Because the vertical size of the rack exceeded the internal height dimensions of the chamber, the rack was positioned horizontally. The side judged to be the most susceptible to a radiated field was oriented toward the source antenna. This side contained the majority of exposed wiring and cabling as well as the access cover to receiver components. The access cover was left open during the tests to approximate a worst-case test condition. When susceptibility measurements were performed on both the receiver and multiplexer, the multiplexer was placed on top of the receiver rack, with the open end of the multiplexer case exposed to the antenna.

2.3.8 Spurious Responses

The response of a superhetrodyne receiver to a frequency other than the desired, or design, frequency is generally termed a spurious response. Spurious responses are formed in the receiver mixer by the nonlinear mixing of an undesired signal and the receiver local oscillator signal. The resultant spurious mix product, which falls within the receiver intermediate frequency passband, can interfere with the reception and recovery of the desired signal information.

Spurious response frequencies for a single conversion receiver are identified by the equation:

$$f_s = \frac{p\, f_{LO} \pm f_{IF}}{q} , \tag{1}$$

where
f_s = spurious response frequency,
f_{LO} = receiver local oscillator frequency,
f_{IF} = receiver intermediate frequency,
p = integer (0, 1, 2, 3, ...),
q = integer (1, 2, 3, ...), and
$\pm$ = designates plus and minus conversions.

Equation 1 is generally referred to as the spurious response equation although the desired response is contained among the frequencies identified by this equation. For the desired response, the integers p and q have the value one, indicating that the fundamental frequency of the local oscillator is mixed with the desired signal to produce the desired response. (In some cases a harmonic of the base local oscillator frequency is used for the mixer injection frequency, and the value of p for the desired response is equal to that harmonic number.)

To determine the theoretical response frequencies for a given receiver, the receiver local oscillator and intermediate frequencies are inserted in Equation 1, and f_s is computed for each of the possible combinations of p and q. The computation results provide a mathematical identification of all undesired signal frequencies which could possibly cause a receiver spurious response. Spurious responses are typically identified by the p value, q value, and IF sign in the form p, q (sign).

From a theoretical viewpoint, Equation 1 implies that an infinite number of response frequencies can be generated within a receiver. In practical receivers, spurious responses may or may not occur depending upon the rejection afforded to undesired signals by the RF selectivity and mixer stages, the levels of undesired signals coupled to the receiver, and the frequency spacing between the undesired signals and the receiver local oscillator signal.

Under the PAVE PAWS interference study, Equation 1 was used primarily to identify those spurious responses which occurred during the receiver susceptibility measurements. Proper identifications were established by inserting the measured spurious response frequency and the receiver local oscillator and IF frequencies into Equation 1, and then selecting the p and q values and the sign of the IF necessary to establish equality in the equation. For example, susceptibility measurements performed on the SYNTOR mobile receiver revealed a spurious response at a frequency of 429.8 MHz (center frequency of response). Inserting the local oscillator frequency (440.5 MHz) and the IF (10.7 MHz) into Equation 1 gives:

$$f_s = \frac{p(440.5) + (10.7)}{q} \qquad (2)$$

In order for Equation 2 to yield an f_s of 429.8 MHz, p must be 1, q must be 1, and the IF sign must be negative. This response is thus the 1, 1(-) spurious response which is normally called the image response.

It should be noted that many of the test specimen UHF receivers were double conversion (i.e., two mixer stages) rather than single conversion receivers. In double conversion receivers, a relationship different from that given in Equation 1 is required if spurious responses are generated from a combination of mix products in both mixer stages. However, since no responses involving both mixer stages were noted during the susceptibility measurements, a discussion of spurious responses in double conversion receivers is not presented. Equation 1 was sufficient to identify all responses which were measured.

2.3.9 Interference Pulse Width, Pulse Repetition Frequency, and Chirp Width Effects

When a victim equipment is subjected to a pulsed interference signal, the susceptiblity of the equipment will generally depend upon the signal pulse width (PW) and pulse repetition frequency (PRF). Specific effects of these two parameters will depend upon the design/response characteristics of the equipment circuitry. Some circuits may respond to the peak power or voltage in a pulse, some may respond to pulse energy, and others may respond to the average power contained in the pulse train. Also, the performance of a equipment may be significantly degraded if the PRF of the interference signal is close to the operating frequencies of internal circuits. Thus interference susceptibility measurements involving pulsed interference must include investigations of PW/PRF effects.

Because of the relatively large number of test specimen UHF receivers and associated test parameters, it was desirable to limit, if possible, the number of individual tests in which PW/PRF/chirp width effects were to be measured. For this reason, exploratory measurements were performed on selected UHF receivers to determine the effects of these parameters on interference susceptibility thresholds. The results of these measurements, which are documented in Section 2.5, revealed that the effects of PW and PRF on the susceptibility thresholds of the test specimen UHF receivers were relatively minor. Hence the selection of a PW and PRF for susceptibility measurements on the set of test specimen UHF receivers was somewhat arbitary, and the choice was based primarily on that PW/PRF combination which facilitated the measurement of detectable interference.

Since only one test specimen microwave receiver and multiplexer were provided for testing, the need to maximize the number of test variables was minimal. The effects of PW and PRF were thus recorded on each of the five microwave receiver channels which were tested. The results of these test are also documented in Section 2.5.

A frequency modulated pulsed signal is typically referred to as a "chirped" signal. Chirping involves sweeping the RF frequency of the pulsed signal over a given range during the time period of the pulse. Note that chirping does not change the pulse width or pulse repetition frequency. Generally, the chirp range or width has an impact only on frequency dependent cases of receiver interference (co-channel interference or spurious responses). For example, for a non-chirped signal, a receiver spurious response would occur at a discrete frequency. For a chirped signal, the response would occur over the total chirp range.

Exploratory measurements were performed on several of the test specimen receivers to evaluate possible chirp width effects on receiver susceptibility. During these measurements, the chirp width was varied over a range from approximately 100 kHz to 1 MHz. As expected, no effects of chirp width on receiver susceptibility were noted except for variations in the "width" of spurious responses. For this reason, a chirp width of 1 MHz was selected for all receiver susceptibility measurements.

2.3.10 Interference Frequency Effects

The susceptibility of a receiver to interference is largely dependent upon the frequency of the interfering signal. For interfering signal frequencies which are not related to internal receiver frequencies, relatively large signal levels are usually required to affect receiver performance. On the other hand, receivers are likely to be highly susceptible to frequencies which fall near or at the receiver tuned frequencies or spurious response frequencies. Since susceptibility levels as a function of frequency can only be determined accurately through measurements, a large portion of the measurement program was directed toward measurements of the effects of frequency on receiver susceptibility thresholds.

2.4 Test Configurations

2.4.1 General

Two basic test configurations were employed in the receiver susceptibility tests: (1) a closed-system configuration in which the simulated PAVE PAWS signal was injected directly into the antenna terminals of the receiver under test; and (2) an open-system configuration in which the test specimen receivers were exposed to the radiated field of the interference signal. The closed-system configuration permitted susceptibility evaluations to be performed at relatively low interference signal power levels, thus providing much easier control over interference signal parameters. This configuration also facilitates control over the desired signal parameters. The closed-system configuration was used primarily in exploratory measurements to determine the effects of interference signal pulse width, pulse repetition frequency, and chirp width and desired signal level on receiver susceptibility thresholds. Receiver spurious responses, effects of receiver squelch, and effects of interference signal spectral characteristics were also investigated using this configuration. Each UHF receiver underwent closed-system tests except for the Handi-Talkies, which did not have accessible antenna terminals. Closed-system tests were not performed on the microwave receiver since its wave guide input precluded the direct injection of signals at frequencies below the cut-off frequency of the guide.

The open-system configuration was used to simulate the radiated interference environment of the PAVE PAWS radar. In this configuration, the test specimen receivers (and antenna when applicable) were exposed to the radiated signal. Open-system tests reflect all possible modes of interference coupling (antenna, case, power line, etc.) and provide the most realistic assessment of equipment susceptibility. The primary test variables in this configuration were interference signal frequency and test specimen orientation, since most of the other variables (desired signal level, interference signal pulse width, pulse repetition frequency, etc.) were held fixed based on the results of the closed-system exploratory tests. However, checks on all test parameters were made to ensure that their previously determined influence on susceptibility thresholds were not altered by the open-system test configuration.

2.4.2 Interference Signal Source

The signal source which was configured to simulate the characteristics of the PAVE PAWS radar is illustrated in Figure 1. The key element of this source is the pulse/ramp generator shown in the lower left-hand corner of the figure. This generator, which was designed and constructed by Georgia Tech, provides an output pulse (and ramp) whose width (PW) and repetition frequency (PRF) can be varied over ranges which are generally compatible with those indicated for the PAVE PAWS signal [1]. The PW is variable over a 180 μs to 17 ms range and the PRF can be varied from 0.66 Hz to 100 Hz.

Figure 2 illustrates the pulse and ramp outputs from the generator. The two outputs are synchronized and the width and repetition frequency of both outputs are controlled independently by the same PW and PRF adjustments.

The pulse output of this pulse/ramp generator is fed to the amplitude modulation (AM) input port of an HP-8640B signal generator. The ramp output is connected to the frequency-modulation (FM) input port of the same signal generator. The output of the signal generator is thus a chirped, RF pulse train whose:

(1) RF frequency (420 - 450 MHz) is controlled by the signal generator frequency control,

(2) Pulse amplitude (up to approximately +20 dBm peak) is controlled by the signal generator output attenuator setting,

(3) PW and PRF are controlled by the adjustments on the pulse/ramp generator, and

(4) Chirp width is controlled by the signal generator peak duration (of FM modulation) control.

The pulse and ramp outputs were also routed to a dual channel oscilloscope for monitoring purposes and for establishing the desired PW and PRF values.

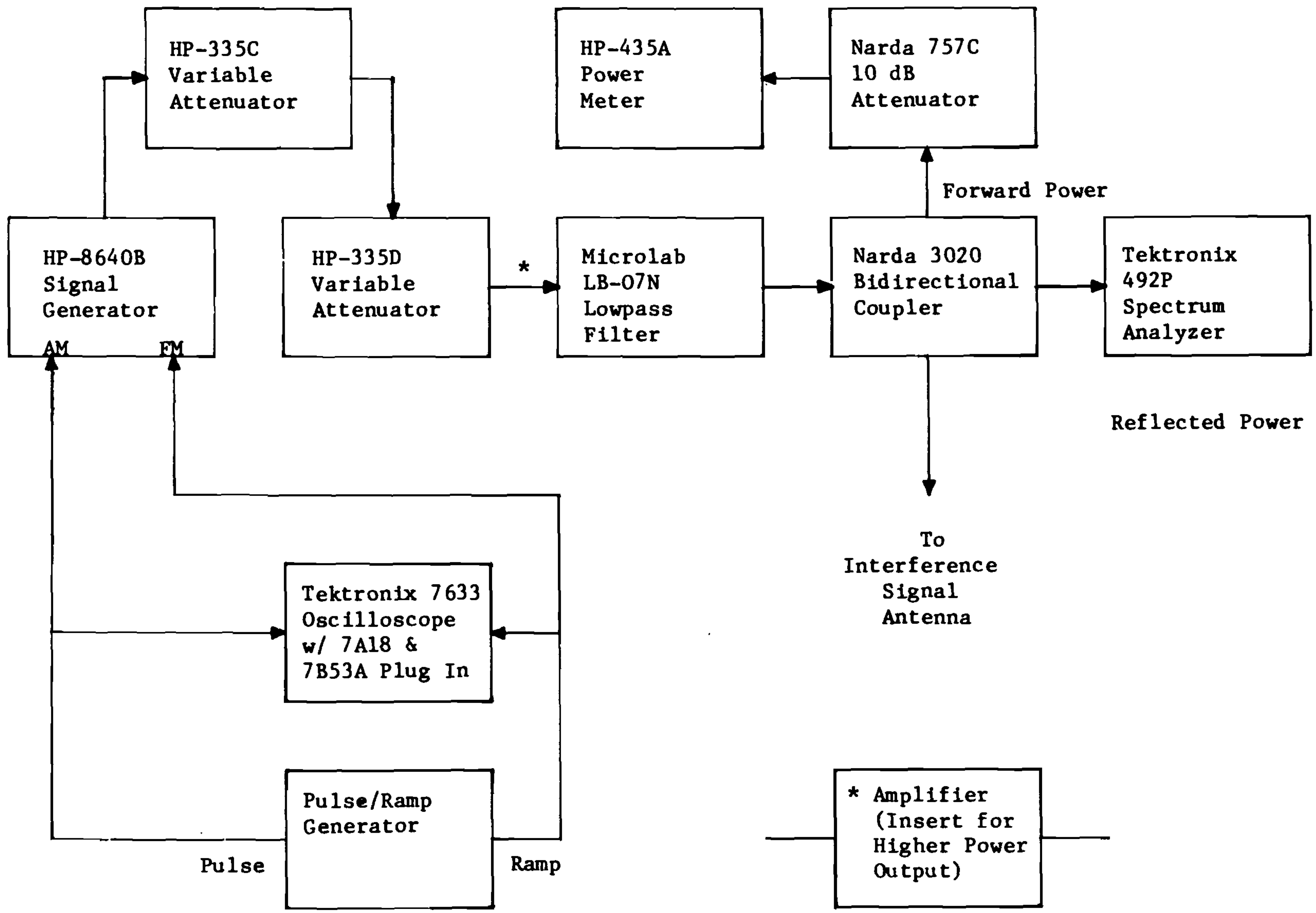


Figure 1. Interference Signal Source.

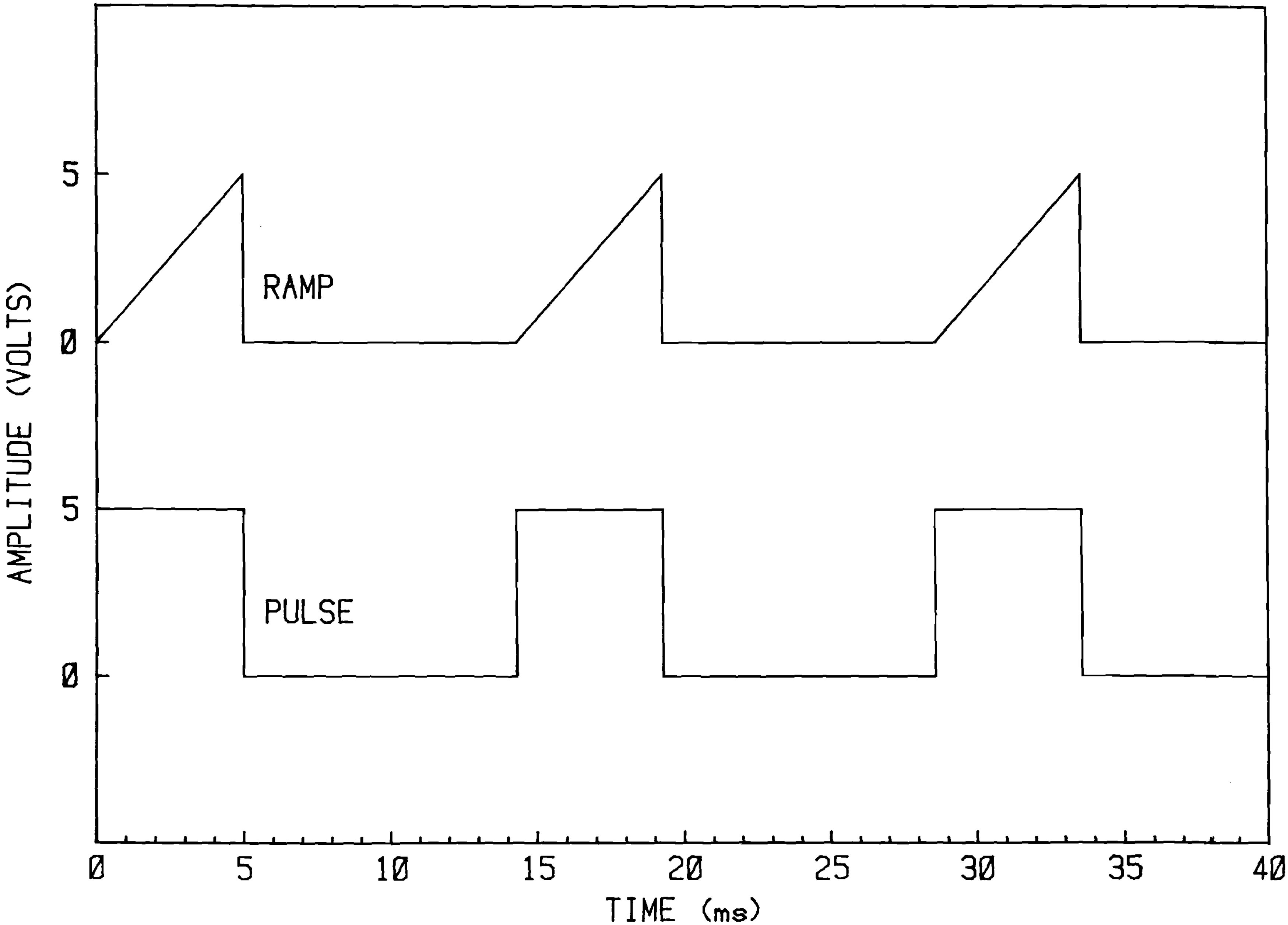


Figure 2. Output of the Interference Signal Source Pulse/Ramp Generator.

In performing the susceptibility measurements (particularly during open-system tests), it was often required that the signal generator be operated near its maximum power output level. At these levels, there is the possibility that the signal generator will not be correctly calibrated -- in other words, the output attenuator reading will not truly represent the actual output power. For this reason, the signal generator was set for maximum output, and control of the RF pulse train amplitude was exercised through the use of the two variable attenuators shown in Figure 1.

The low pass filter (700 MHz cutoff) shown in the Figure 1 was used to suppress harmonics of the RF signal, and the bidirectional coupler was used to sample the output signal for monitoring and control purposes. A sample of the signal was routed through an attenuator (for protection purposes) to a power meter for monitoring and calibrating the signal amplitude, and to a spectrum analyzer for monitoring the signal spectrum and for adjusting the chirp width.

The simulated PAVE PAWS signal out of the coupler was routed either to the receiver antenna terminals for closed-system measurements or to the interference source antenna for open-system measurements. The spectral characteristics of this simulated signal as measured on the spectrum analyzer is shown are Figure 3. These characteristics correspond to a signal pulse width of 5 ms, pulse rise and fall times of approximately 50 ns, and a chirp width of 1 MHz.

For the open-system susceptibility measurements performed on the microwave receiver and multiplexer, the power out of the signal generator was not sufficient to allow interference thresholds to be detected. It was thus necessary to insert an RF amplifier into the interference signal source configuration as indicated in Figure 1. The particular amplifier used, an Eaton Model 3552B, increased the power output of the interference source to approximately +43 dBm. Since this amplifier is broadband, the spectral characteristics of the interference were not affected by its use.

During exploratory measurements, two other amplifiers were used to boost the output power of the interference source -- a Boonton 230A and a Georgia Tech high power UHF amplifier constructed under a previous program. The

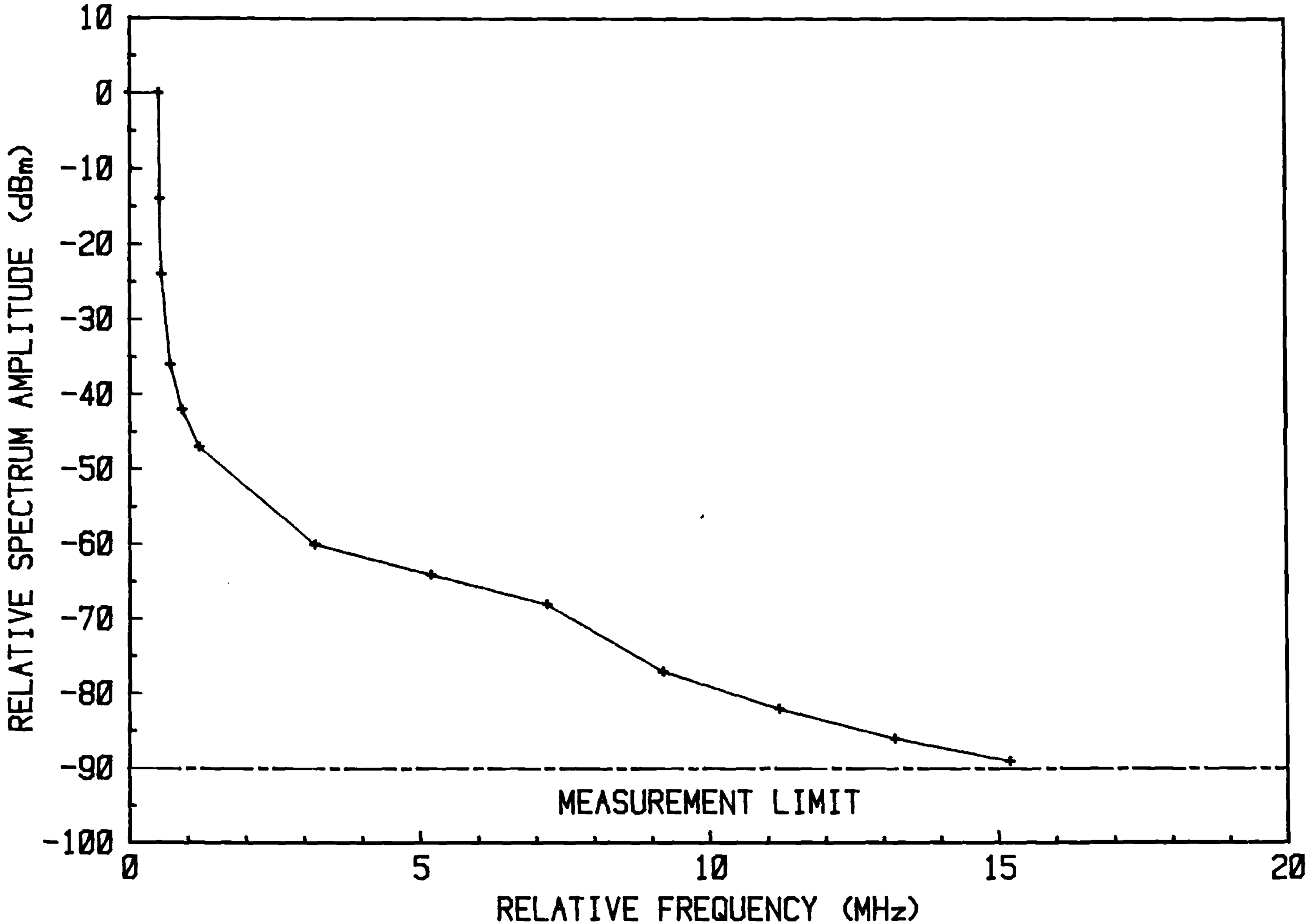


Figure 3. Spectral Characteristics of Simulated Interference Signal.

Boonton and Georgia Tech amplifiers provide outputs of approximately +36 dBm and +60 dBm, respectively. These amplifiers were employed primarily to enable interference mechanisms to be investigated, i.e., whether receiver interference was caused by the peak power of the pulse or by pickup of signal spectral components in the receiver passband. Once these investigations were completed, these amplifiers were no longer used.

2.4.3 Desired Signal Source

2.4.3.1 UHF Receivers

The desired signal source used for susceptibility measurements on the UHF receivers is illustrated in Figure 4. The signal generator used allowed control over all desired signal parameters -- level, frequency, modulation, etc. The output of the signal generator was routed through a bandpass filter to suppress any signal harmonics which might affect the measurement results.

2.4.3.2 Microwave Receiver

The desired signal source for the microwave receiver tests is illustrated in Figure 5. The UHF transmitter, circulator, and fixed attenuators attached to the circulator were supplied by the Georgia Power Company. The remaining components of this source configuration were added to control and calibrate the level of the desired signal input to the test specimen microwave receiver. This input was set to -32 dBm except for tests of desired signal level effects on interference thresholds.

2.4.4 Closed System Tests

2.4.4.1 Basic Test Configuration

A block diagram of the closed-system test configuration is shown in Figure 6. As seen in this figure, the interference signal and the desired signal were combined in a hybrid, whose output was coupled directly into the test specimen receivers' antenna terminal. Since closed-system susceptibility measurements usually involve relatively low interference signal and desired signal power levels, this configuration permits both the

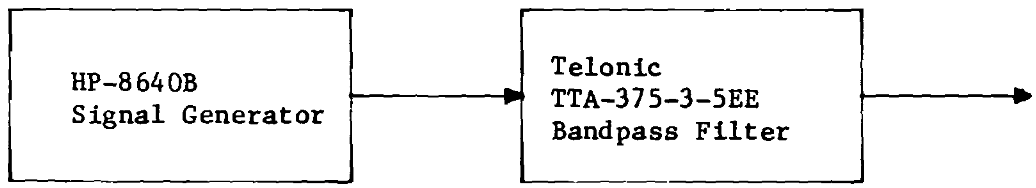


Figure 4. Desired Signal System for UHF Receivers.

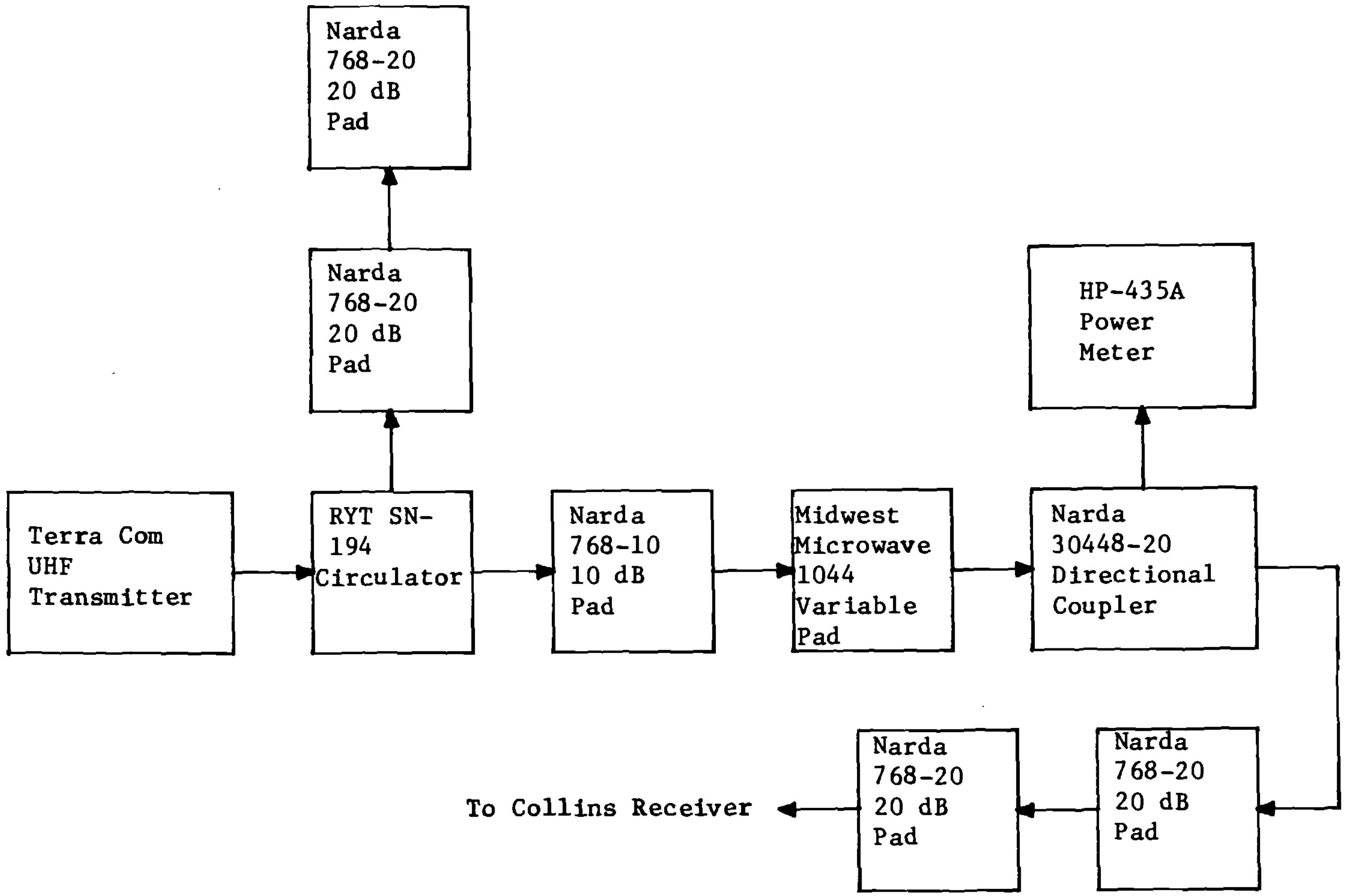


Figure 5. Desired Signal Source for Microwave Receiver.

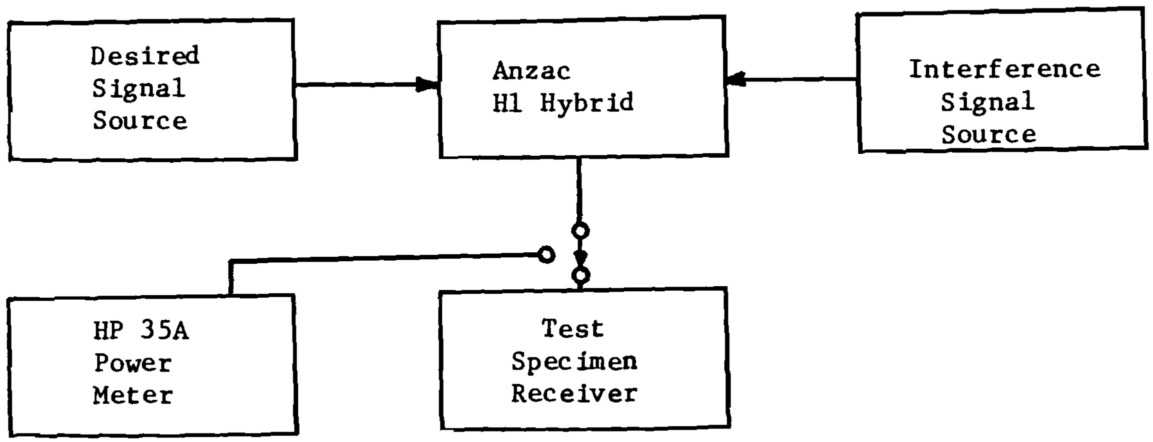


Figure 6. Basic Closed-System Test Configuration for UHF Receiver Tests.

desired and interference signals to be easily varied, controlled, and calibrated. The closed-system configuration was used primarily in exploratory investigations of receiver susceptibility characteristics -- receiver spurious responses, effects of interference on receiver squelch, interference mechanisms, etc. With the interference signal removed, this configuration was also used for brief checks of receiver sensitivity and selectivity to ensure that the receivers were operating "normally" prior to performing interference susceptibility measurements.

2.4.4.2 Closed-System Calibration

The closed-system configuration was calibrated prior to the initiation of closed-system tests. The calibration was performed with a power meter as indicated in Figure 6. The level of both the desired signal and the interference signal was measured at the test specimen receiver antenna terminals as a function of control settings on the desired signal source and interference signal source. Once calibrated, the levels of both signals at the antenna terminal could be read directly, in dBm, from the source control settings.

2.4.5 Open-System Tests

2.4.5.1 General

Several open-system test configurations were used to accomodate the different test requirements of the test specimen UHF and microwave receivers. However, all of these configurations had the following common features:

(1) The tests were performed in an anechoic chamber in order to simulate open-field conditions and to isolate the test environment from extraneous signals.

(2) An interference source antenna was used to establish a controlled and calibrated radiated test environment.

(3) The test specimen receivers were positioned in the chamber so as to satisfy far-field test conditions.

(4) In general, only the interference source antenna and the test specimen receivers were located in the chamber. All other test equipment were located external to the chamber, including the desired signal source, interference signal source, and interference monitoring equipment.

(5) Interference susceptibility measurements were performed for various test specimen orientations as described in Section 2.3.7.

(6) The general procedure for measuring interference susceptibility thresholds was to monitor the audio (and data) outputs of the test specimen while increasing the intensity of the radiated field. That field strength which just produced perceptible interference in the outputs was recorded as the susceptibility threshold.

2.4.5.2 Interference Source Antenna

The simulated PAVE PAWS signal from the interference source was fed to a Georgia Tech designed UHF antenna to establish a calibrated field strength at the test specimen receiver location within the anechoic chamber. The antenna used was a circularly polarized helical antenna with a nominal gain and beam width of 13 dB and 42°, respectively. Over the 420 - 450 MHz frequency range, the gain variation of this antenna is less than 1 dB and the beamwidth variation is less than 5°. The test specimen receiver under test was located approximately eight feet from the center of the antenna to satisfy far-field criteria. A photograph of the antenna is shown in Figure 7.

2.4.5.3 Exposure Field Levels

The interference signal source (without amplifiers) of Figure 1 and the interference source antenna (Figure 7) enabled peak field strength levels up to +9 dBm/m^2 to be achieved at the test specimen position in the anechoic chamber. This maximum level was generally sufficient for all interference susceptibility threshold measurements performed on the test specimen UHF receivers.

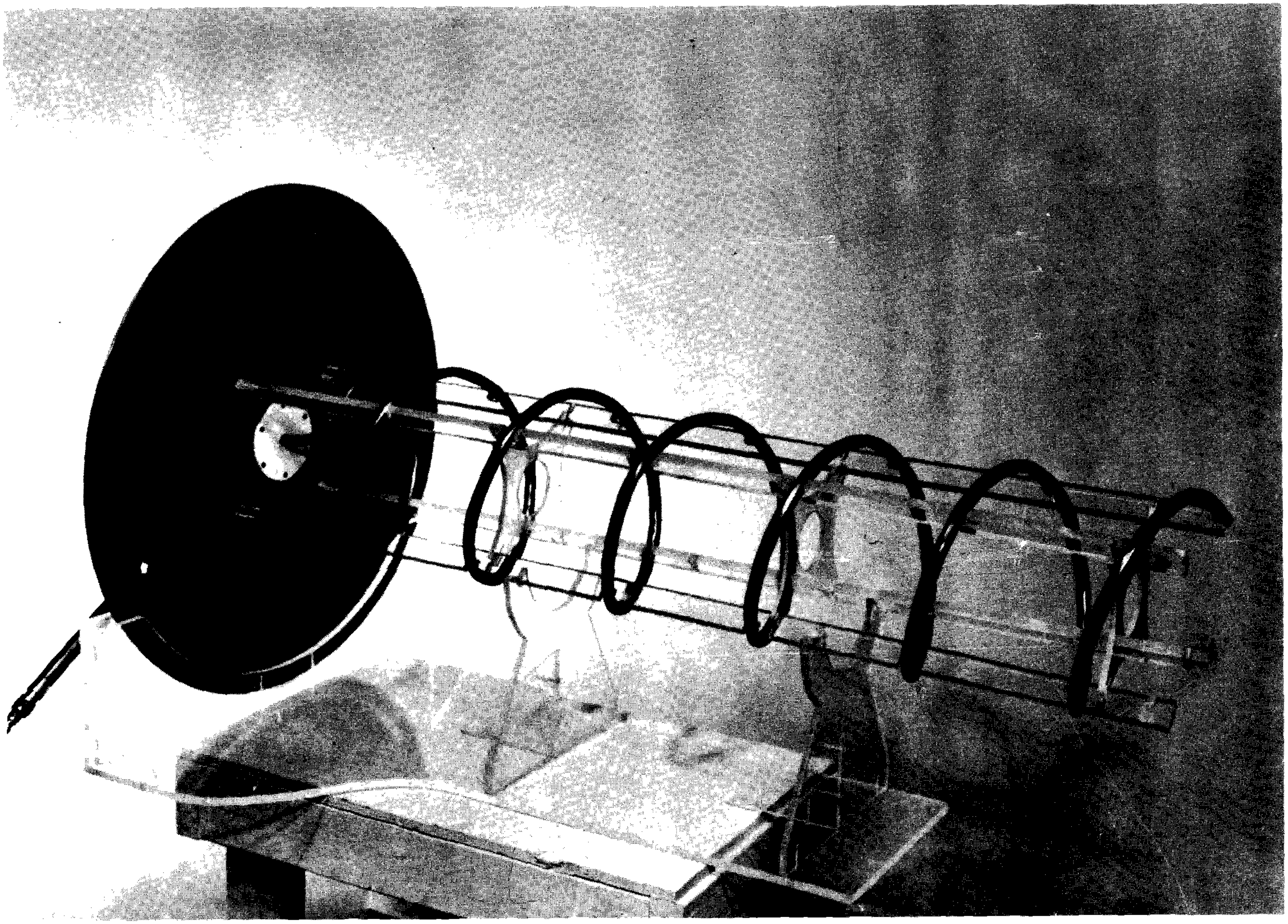


Figure 7. Photograph of Interference Source Antenna

For the microwave receiver tests, a 9 dBm/m^2 field strength level was not sufficient to identify interference thresholds. Hence, for tests performed on this receiver, an Eaton Model 3552B amplifier was inserted as indicated in Figure 1. With this amplifier, peak field strength levels up to 39 dBm/m^2 could be achieved.

Some exploratory measurements were conducted in an open-system configuration in which the interference source power output was increased using a Boonton 230A and a Georgia Tech high power amplifier. These amplifiers permitted field strength levels of 25 dBm/m^2 (Boonton) and 53 dBm/m^2 (Georgia Tech amplifier) to be established. Both of these amplifiers are narrow-band and thus influence the spectral characteristics of the interference signal. For this reason, the amplifiers were used solely in attempts to identify interference mechanisms, and no specific interference threshold data were recorded during their use.

2.4.5.4 Test Configurations (UHF Receivers)

The basic test configurations employed in the UHF receiver susceptibility measurements are shown in Figures 8 through 10. Figure 8 illustrates the configuration used for the SYNTOR, MICOR, and Base Station receivers, which were tested with and without the two test specimen antennas supplied with the receivers (6 ¼ and 38 ½ inch monopoles). Tests without the antennas were conducted by injecting, via calibrated coax cables, the desired signal directly into the antenna terminal of the test specimen receivers. For tests performed with the test specimen antennas connected to the receivers, the desired signal was radiated via a standard gain dipole (Scientific Atlanta Model 15-350). Each of the test specimen monopole antennas was mounted on a one foot by one foot ground plane (to simulate field installations) and set in a fixed position relative to the receiver during tests. These two methods of desired signal injection permitted radiated interference coupling modes -- case alone or case plus antenna -- to be identified.

Figure 9 shows the test configuration used for the UHF repeater. Note that because the repeater antenna was not supplied as a test specimen item (because of its large size), these tests were performed with the desired

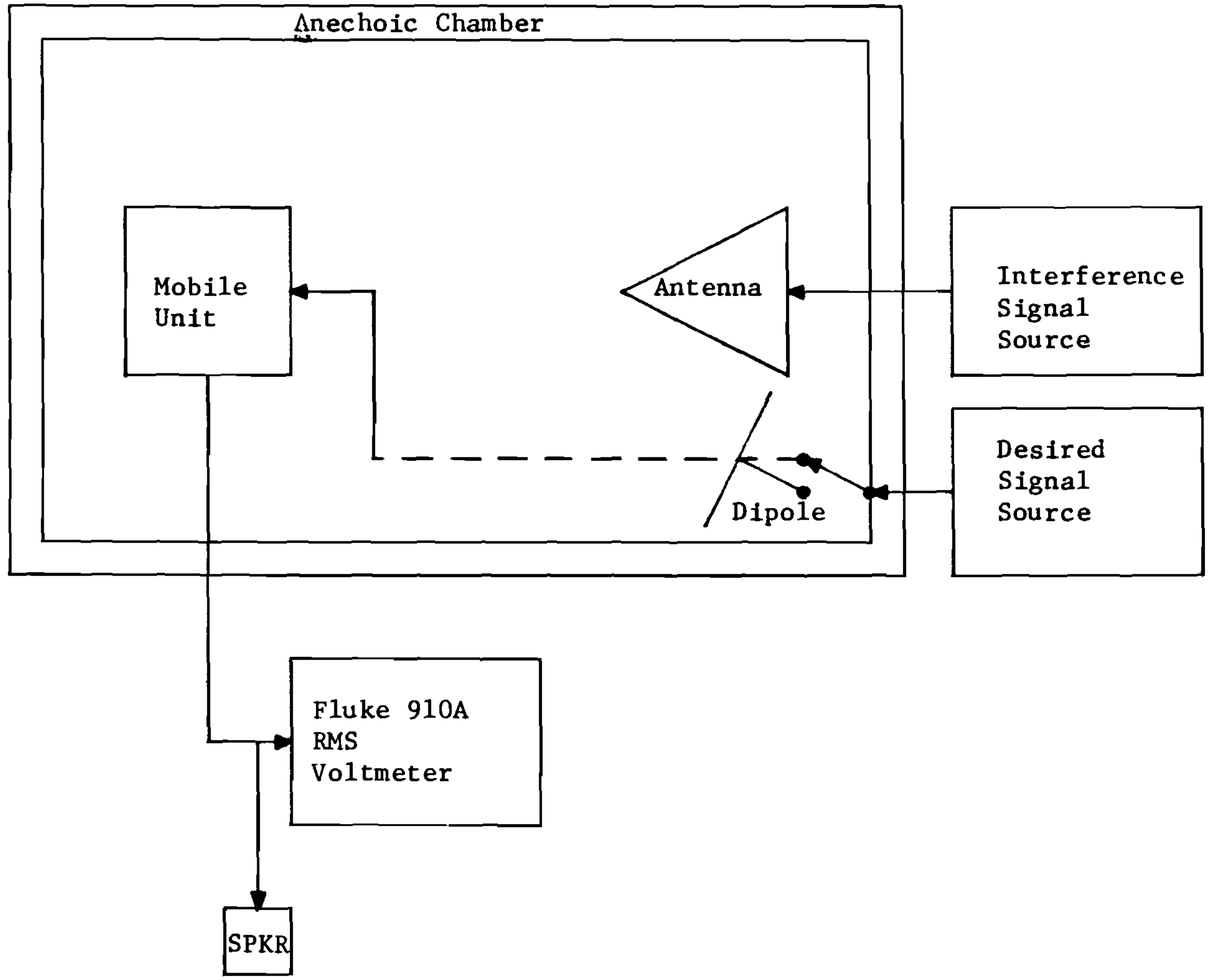


Figure 8. Open-System Test Configuration for SYNTOR, MICOR, and Base Station Receivers.

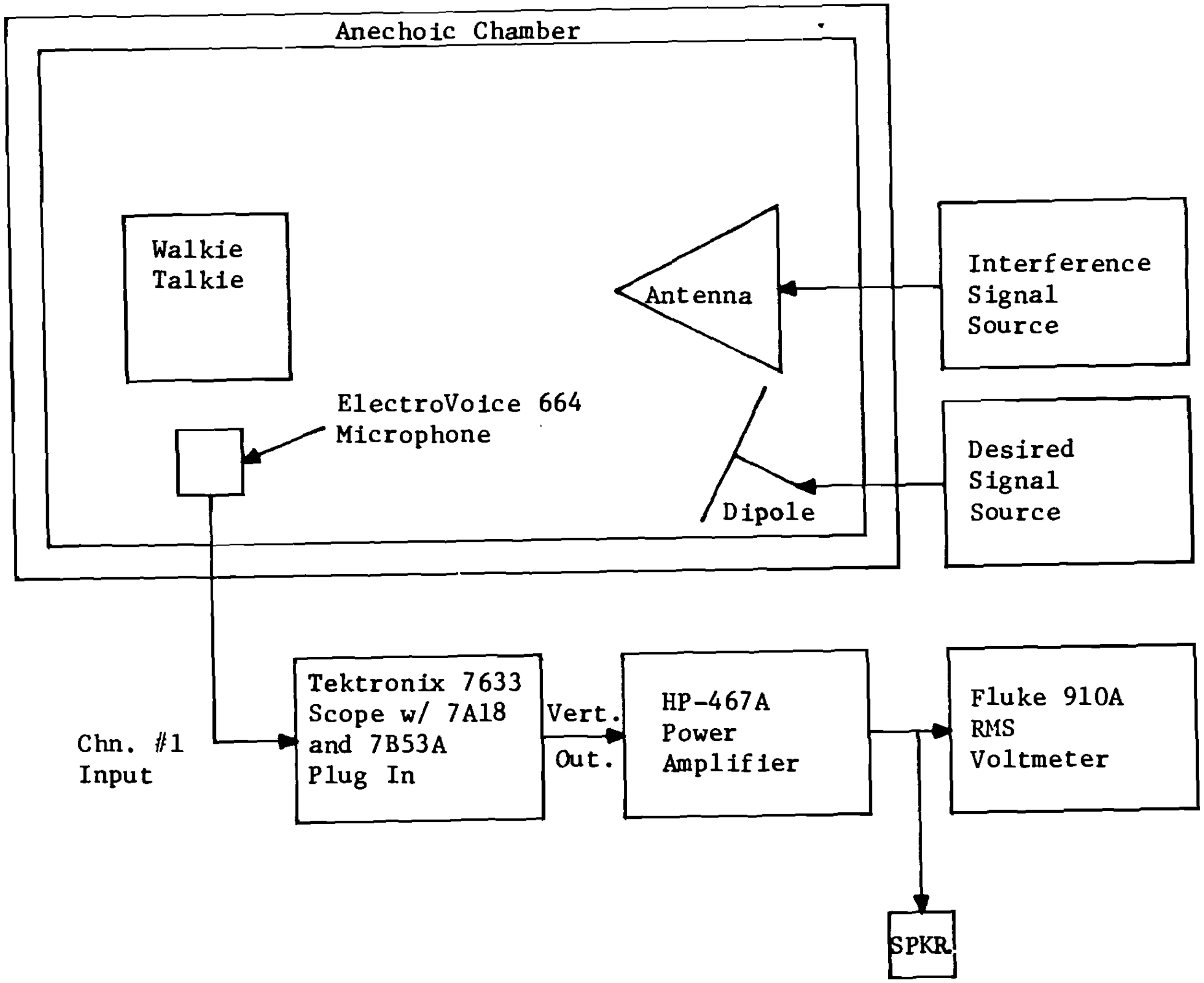


Figure 9. Open-System Test Configuration for Repeater.

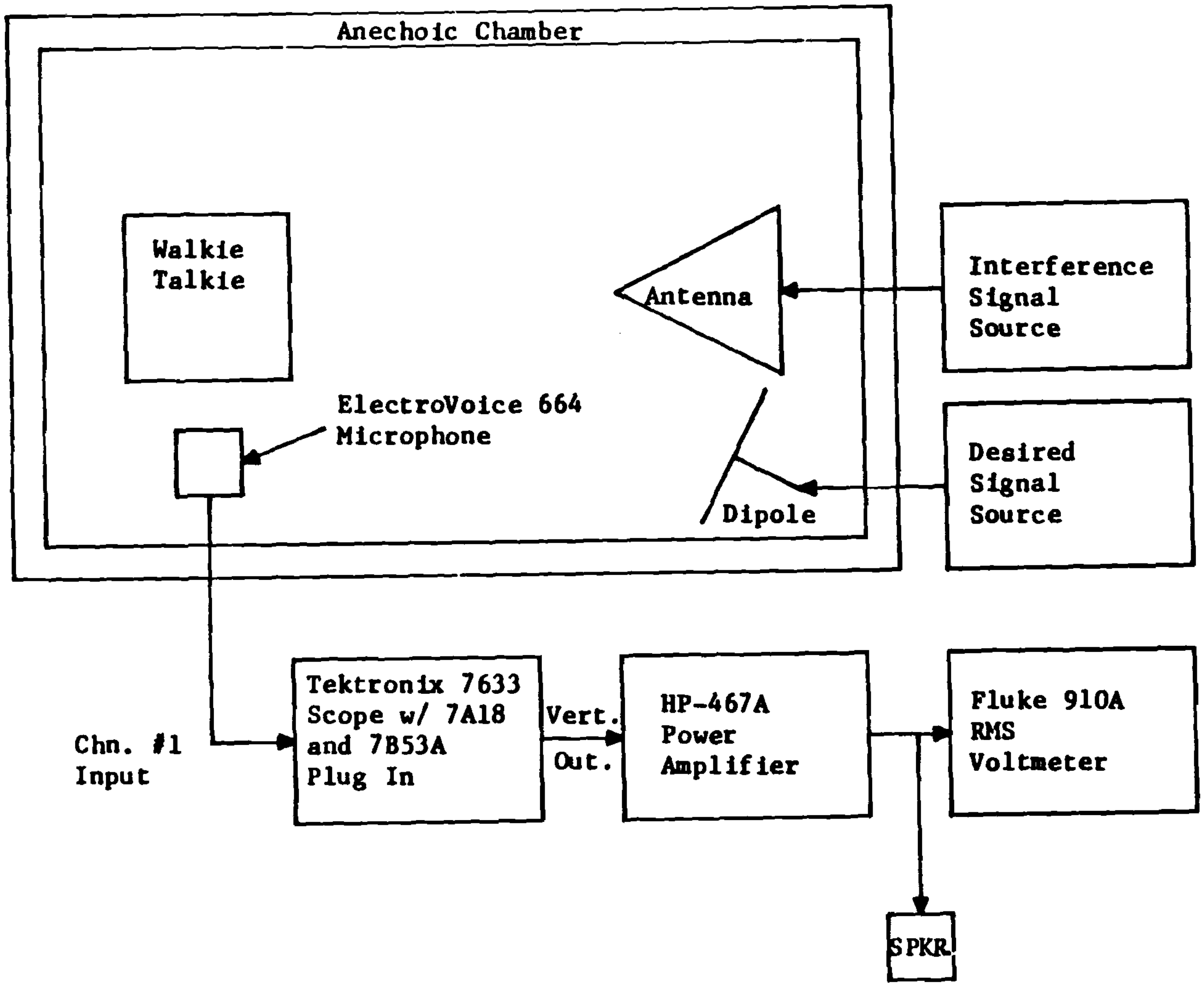


Figure 10. Open-System Test Configuration for Handi-Talkie HT220 and MT500.

signal injected directly into the antenna terminals of the repeater receiver. Also note that since a volume control was not available on the repeater, an oscilloscope and audio amplifier were used to increase the audio signal to the standard test level of 0.53 volts RMS.

The test configuration used for the Handi-Talkies is shown in Figure 10. Since these units had built-in antennas and speakers, the antenna and speaker terminals were not readily accessable. Thus a radiated mode of desired signal injection was used, and a microphone was used to pick up the audio output of the Handi-Talkie. Audio amplifiers were used to increase the audio output to the standard 0.53 volt RMS test level.

2.4.5.5 Test Configurations (Microwave Receiver)

Two test configurations were employed for susceptibility measurements on the microwave receiver/multiplexer. In the configuration shown in Figure 11, only the receiver was exposed to the interference field. Figure 12 shows the setup when both the receiver and multiplexer were radiated. These two configurations allow the susceptibility characteristics of the receiver to be differentiated from those of the receiver/multiplexer combination.

In both test configurations, two types of signals from the receiver were monitored for interference. First, an audio signal was passed from the low level output of the receiver to the multiplexer. The audio output of the multiplexer was then monitored with a headset and an rms voltmeter in a manner identical to that used in the UHF receiver tests. The second signal was a digital signal generated in the ADS-448 modem. This signal was passed from the modem to the multiplexer which modulated it onto the desired signal. This modulated signal was injected into the receiver. The baseband low level output of the receiver was then fed back into the multiplexer and demodulated. From the multiplexer, the digital signal was routed to the modem and was compared to the original transmitted signal by a modem test set. Any bit errors which may have occurred due to interference were indicated and recorded on the modem test set. As noted in the two figures, various low pass filters were used to prevent the interference signal from being injected into the monitoring equipment. Also, the baseband high level output was monitored with a spectrum analyzer for reference purposes.

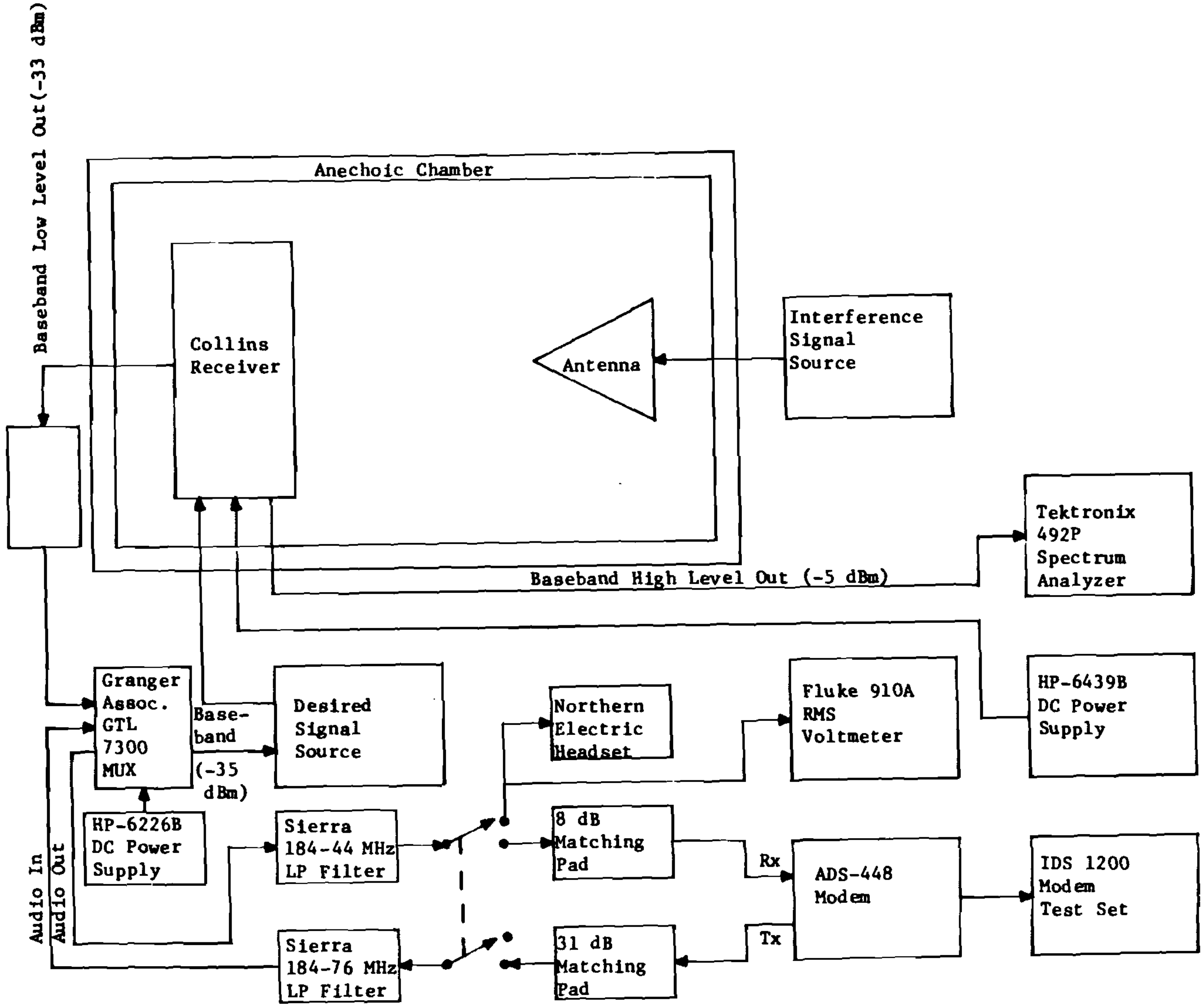


Figure 11. Open-System Test Configuration for Microwave Receiver.

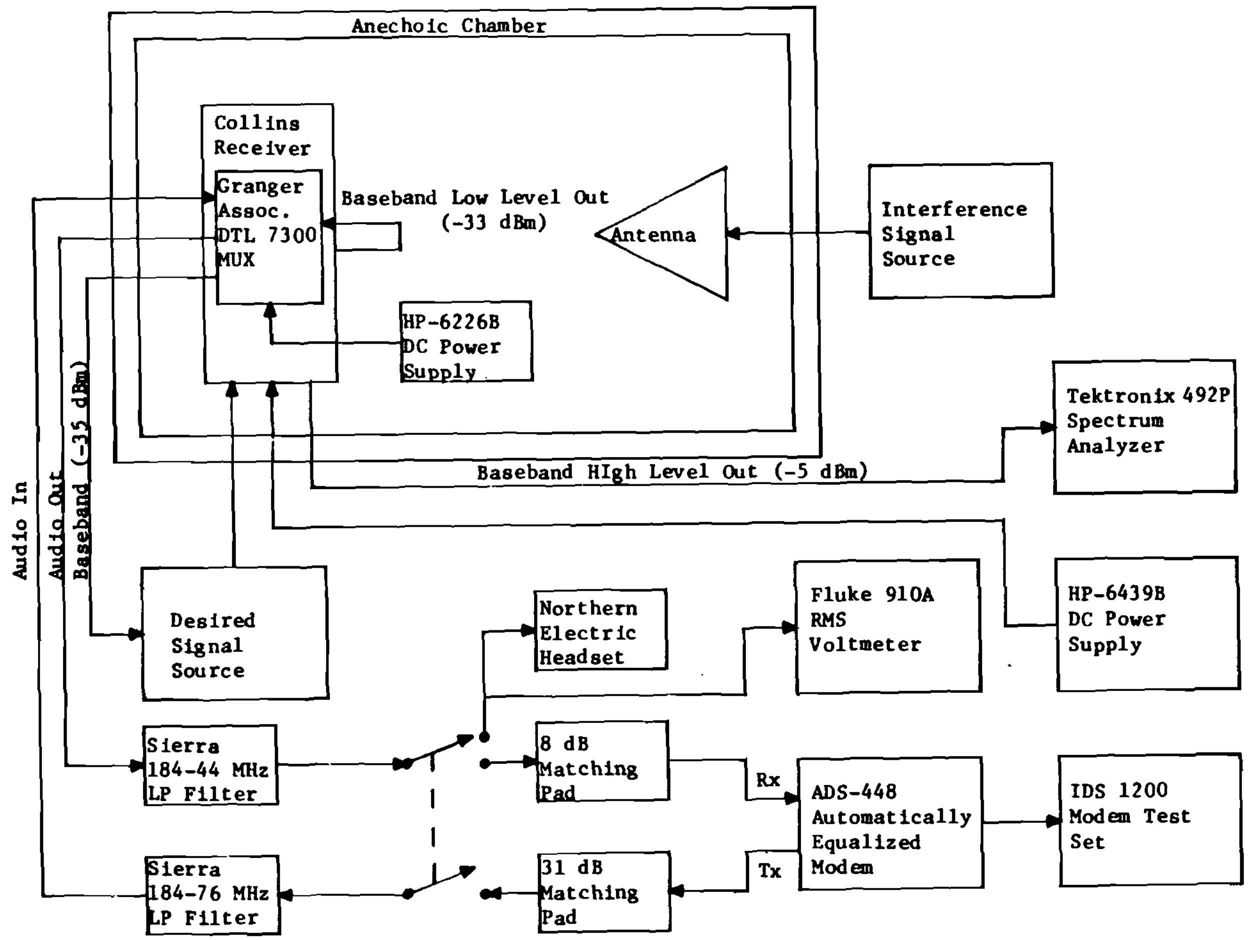


Figure 12. Open-System Test Configuration for Microwave Receiver/Multiplexer.

2.4.5.6 Open-System Calibration

Prior to the initiation of open-system susceptibility tests, the field strength of the simulated PAVE PAWS signal at the receiver position within the anechoic chamber was calibrated with respect to the control settings of the interference signal source. The calibration was accomplished by inserting a standard gain tuned dipole at the receiver location and measuring the interference signal power on a power meter. The readings were then converted to decibels relative to one milliwatt per meter squared (dBm/m^2). The calibration procedures were repeated for each of the power amplifiers used in the interference signal source. Once the field calibration was complete, no other calibration efforts were required other than periodic checks to ensure proper operation of the equipment.

2.5 Closed-System Test Results (UHF Receivers)

2.5.1 General

The closed-system tests involved both exploratory investigations of test parameter effects and measurements to define the antenna conducted susceptibility thresholds of the test specimen UHF receivers as a function of interference frequency. The exploratory measurements were performed to identify test parameter effects (desired signal level and interference signal pulse width, pulse repetition frequency, and chirp width) and to determine the effects of interference on receiver squelch operation. Closed-system tests and results are summarized below.

2.5.2 Exploratory Investigations

2.5.2.1 Effects of Desired Signal Level

The results of measurements performed to determine the effects of desired signal level on UHF receiver susceptibility thresholds are shown in Figure 13. This figure shows, for three interference signal frequencies, the relative susceptibility level of the test specimen MICOR and SYNTOR receivers

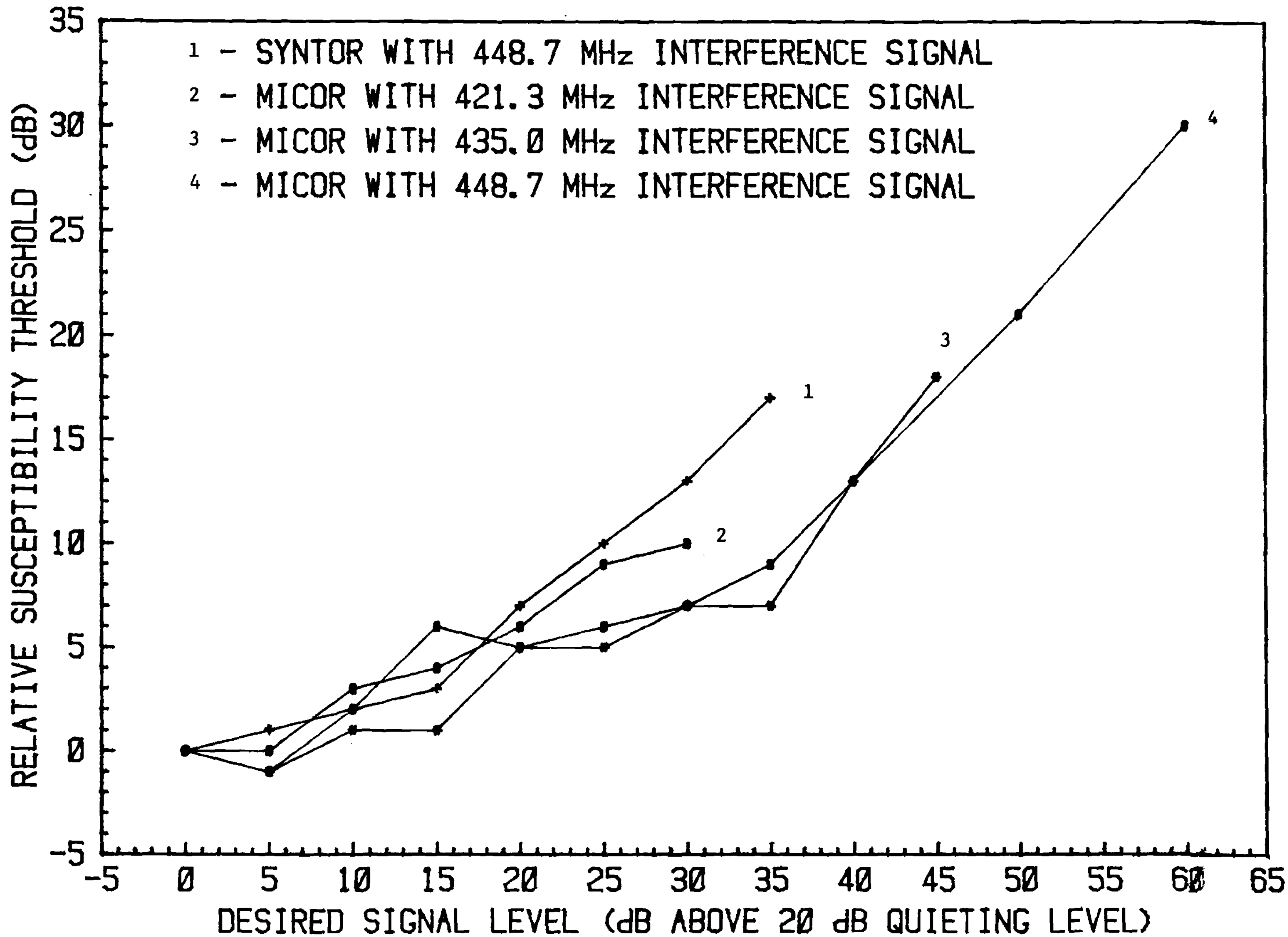


Figure 13. Illustration of Effects of Desired Signal Level on UHF Receiver Interference Susceptibility Thresholds.

plotted as a function of desired signal level. The level of desired signal used in the tests ranged from that level used to define the sensitivity of an FM receiver to a value approximately 60 dB above this level. This range was considered sufficient to cover the range of desired signal levels typically encountered in an operating environment.

Note from the figure that the receiver was most susceptible at the 20 dB quieting level, which was expected since the gain of the receiver is near maximum at this level. Based on these data, a desired signal input 10 dB above the 20 dB quieting level was selected for susceptibility measurements on the test specimen UHF receivers. This particular input level was selected as a trade-off between maximum receiver susceptibility (obtained at the 20 dB quieting level) and the ease of performing interference threshold measurements. The additional 10 dB reduction in the receiver noise floor made it much easier to listen for, and detect, the interference signal threshold.

2.5.2.2 Effects of Pulse Width, Pulse Repetition Frequency, and Chirp Width

Measurements of the effects of interference signal pulse width, pulse repetition frequency, and chirp width were performed on several of the test specimen UHF receivers. Typical results of PW, PRF, and chirp width on interference thresholds are illustrated in Figures 14, 15, and 16, respectively. Note from these figures that none of these three parameters have a significant effect on interference threshold levels. These results were expected since these parameters do not appreciably change the spectral characteristics of the interference signal which fall within the tuned frequency passband of the UHF receivers. Since UHF receiver susceptibility proved to be relatively independent of these three test parameters, all future tests were conducted using a 5 ms PW, a 70 Hz PRF, and a 1 MHz chirp width. These particular values were selected primarily to facilitate the monitoring and detection of thresholds.

2.5.2.3 Squelch Tests

Tests were performed on each UHF receiver to determine if the simulated PAVE PAWS signal would break receiver squelch. In these tests, the desired

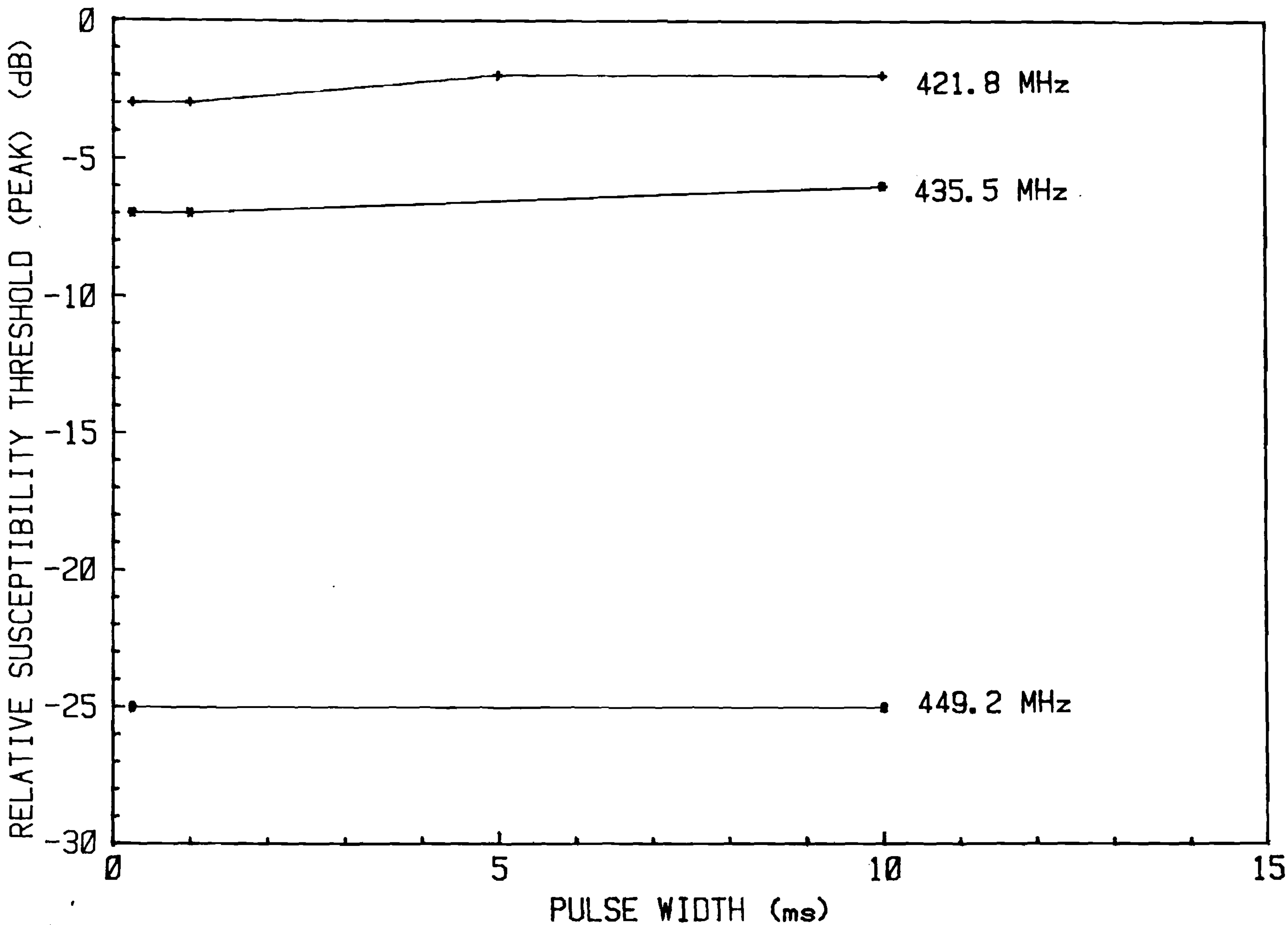


Figure 14. Relative Susceptibility Thresholds of MICOR Receiver versus Interference Signal Pulse Width (PRF = 70 pps, Chirp = 1 MHz, Desired Signal Level = 20 dB Quieting + 10 dB).

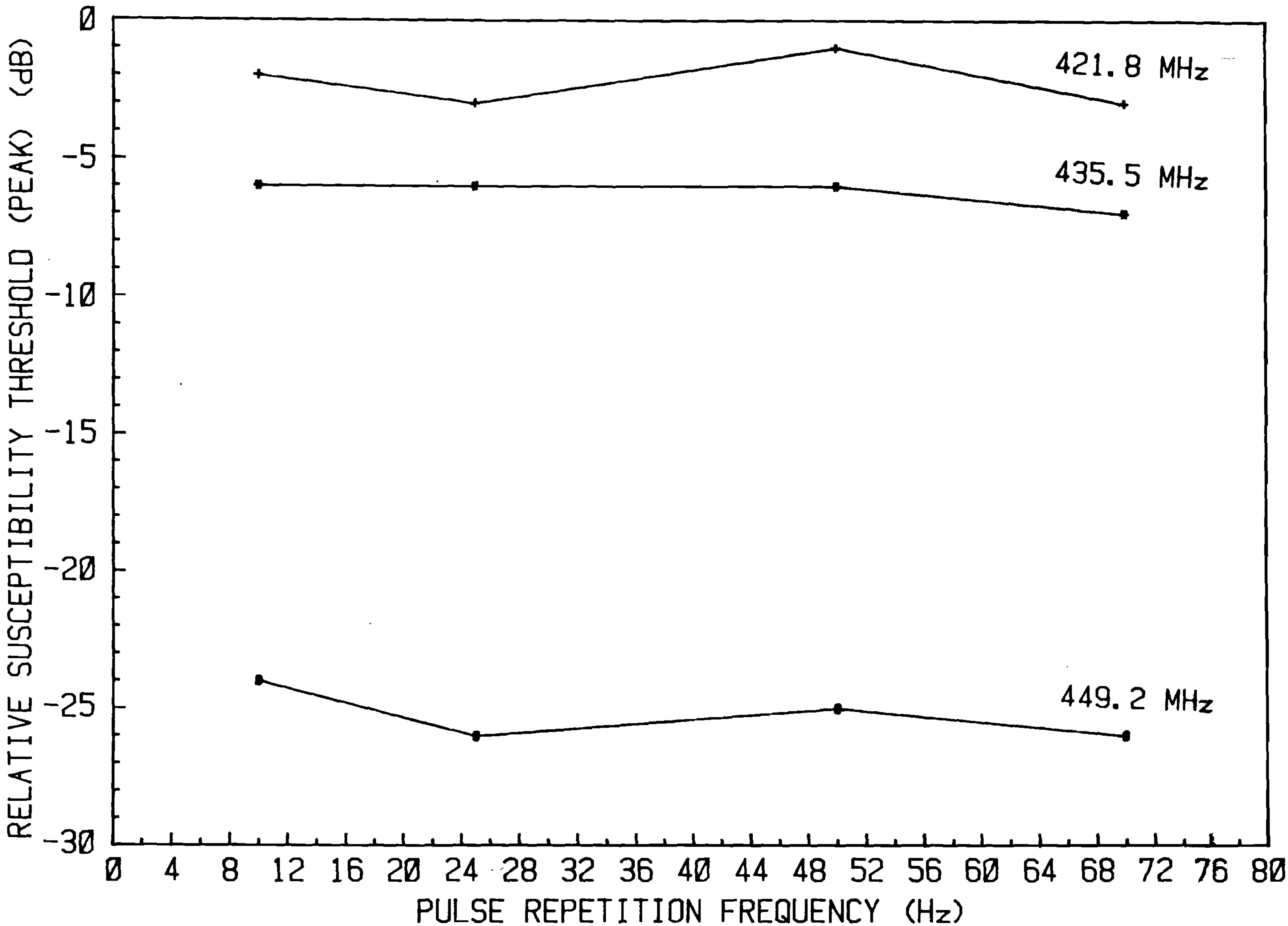


Figure 15. Relative Susceptibility Thresholds of MICOR Receiver versus Interference Signal Pulse Repetition Frequency (PW = 5 ms, Chirp = 1 MHz, Desired Signal Level = 20 dB Quieting + 10 dB).

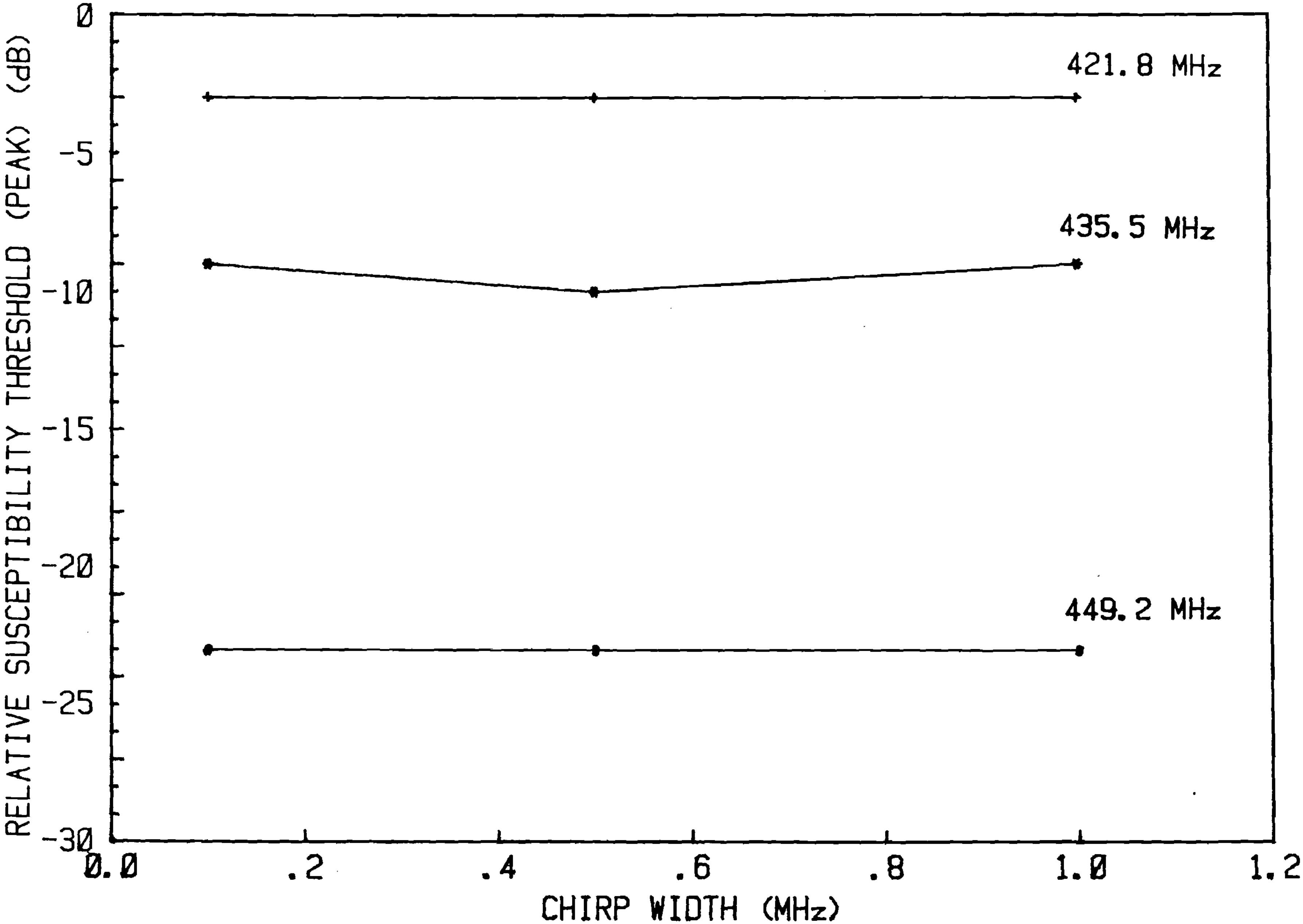


Figure 16. Relative Susceptibility Thresholds of MICOR Receiver versus Chirp Width (PW = 5 ms, PRF = 70 pps, Desired Signal Level = 20 dB Quieting + 10 dB).

signal level was set to yield 20 dB of receiver quieting, and the interference signal was set to a peak level of 0 dB and swept over the 420 - 450 MHz frequency range. The tests were conducted for various squelch settings and for various combinations of interference signal parameters (pulse width, pulse repetition frequency, and chirp width). Squelch was not broken on any of the UHF receivers.

2.5.3 Closed-System Susceptibility Thresholds

The antenna conducted susceptibility of the MICRO, SYNTOR, Base Station, and Repeater receivers was measured using the closed-system test configuration of Figure 6. For these measurements, the desired signal level was set to the reference level (20 dB quieting + 10 dB), and the interference signal PW, PRF, and chirp width were set to 5 ms, 70 pps, and 1 MHz, respectively. Susceptibility thresholds were then recorded over the 420 - 450 MHz frequency range.

The data recorded during these tests are illustrated in Figures 17 through 20. These figures show the interference susceptibility thresholds versus interference frequency for the SYNTOR, MICOR, Base Station, and Repeater receivers, respectively. (Note: While data were recorded for interference frequencies up to the receiver tuned frequency (451.2 MHz), the primary frequency range of concern for PAVE PAWS is 420.8 to 449.2 MHz, as explained in Section 3.2.4.1.)

Note that the characteristics of the data in the figures basically resemble a mirror image of the spectral characteristics of the interference signal depicted in Figure 3. When the center frequency of the interference signal is at the tuned frequency of the receiver, the receiver is responding to the energy at the center or peak of the spectrum. As the frequency of the interference signal is tuned over a range from approximately 451.2 MHz to 435 MHz, the receiver is simply "measuring" the spectral characteristics of the pulsed signal. This fact is further illustrated in Figure 21, where the measured spectrum of Figure 3 is inverted and plotted over the susceptibility data of Figure 17. This same trend was noted in the susceptibility data on the MICOR, Base Station, and repeater receivers. Thus it can be generally

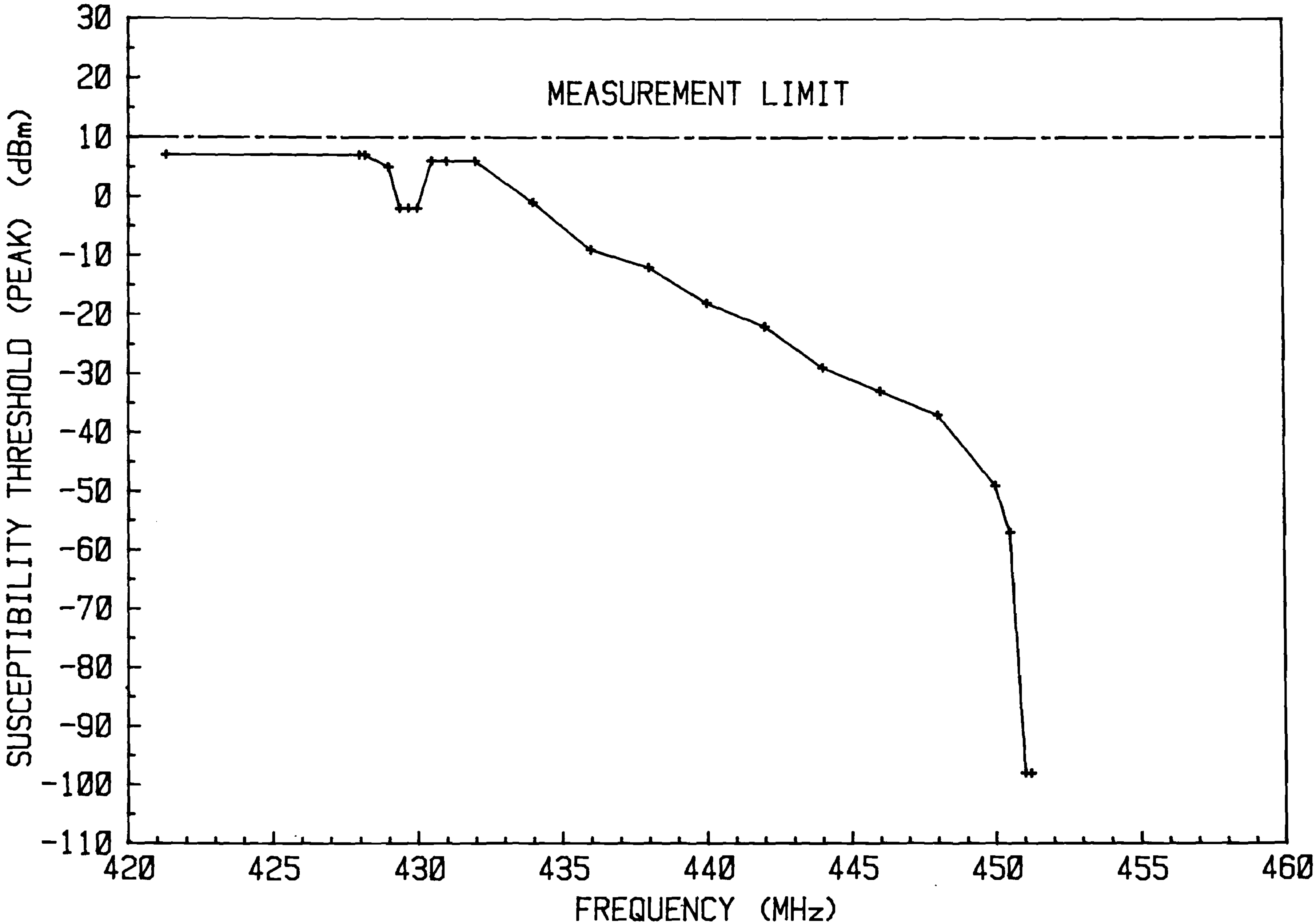


Figure 17. Closed-System Interference Susceptibility Thresholds versus Frequency for SYNTOR Receiver.

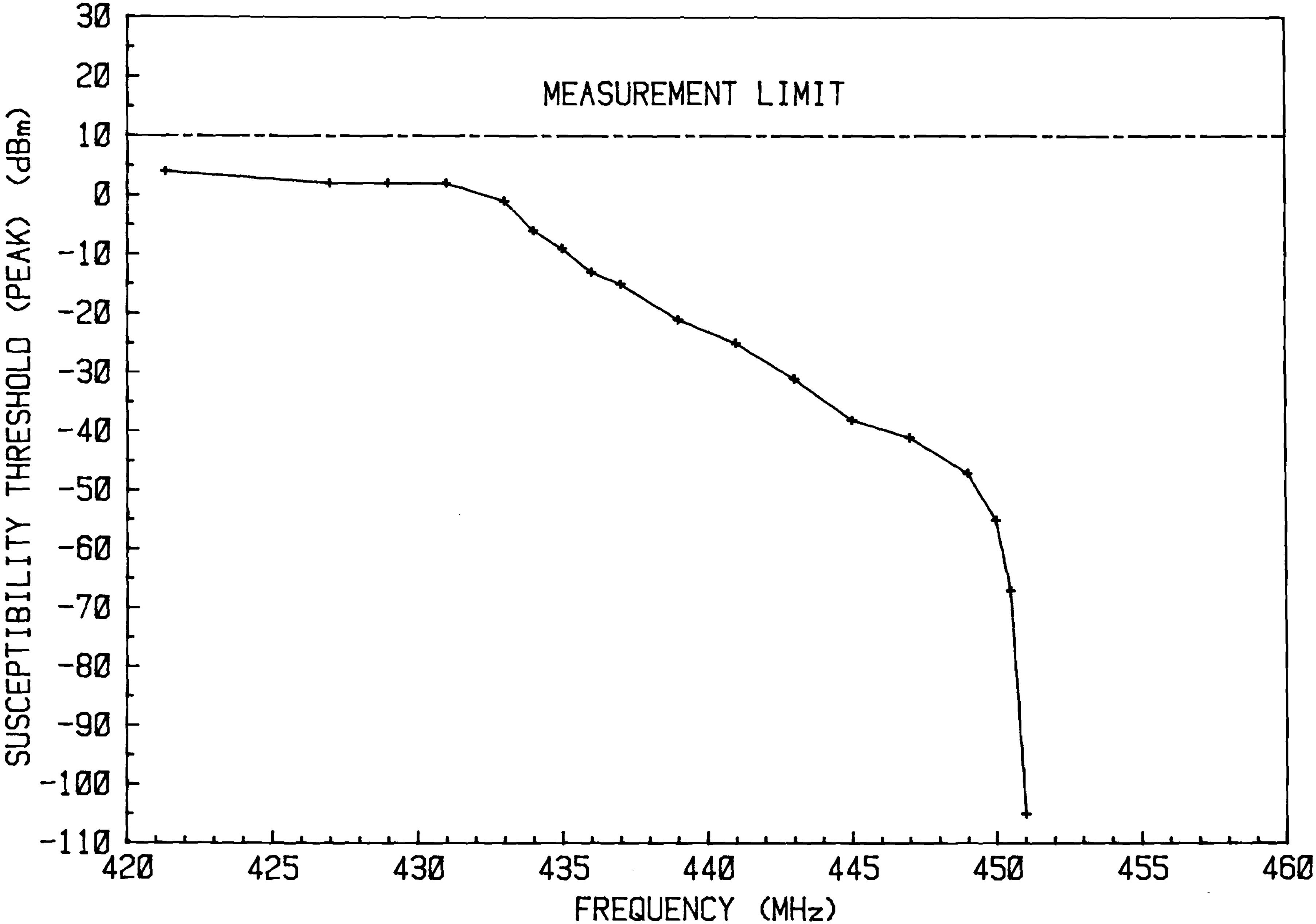


Figure 18. Closed-System Interference Susceptibility Thresholds versus Frequency for MICOR Receiver.

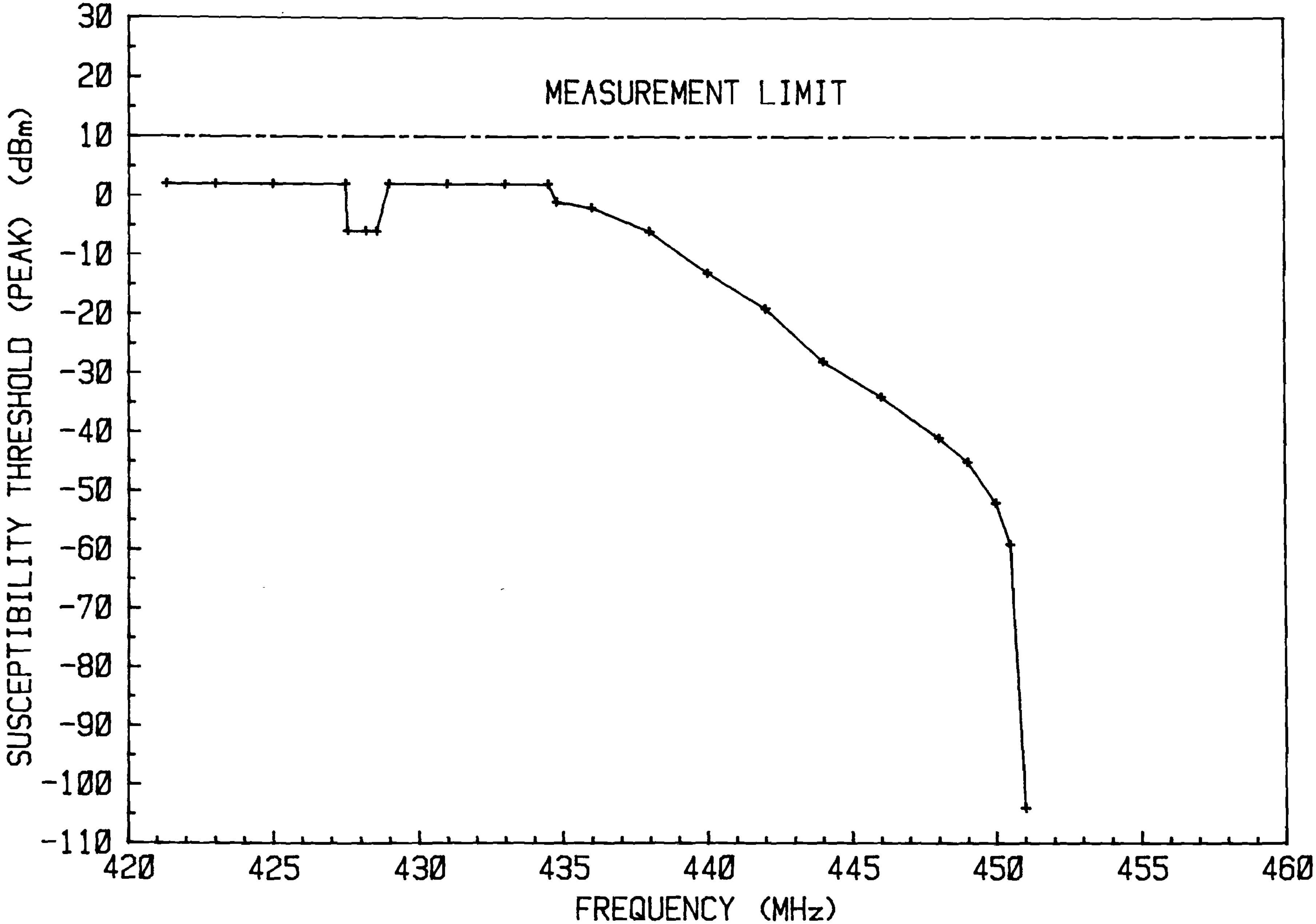


Figure 19. Closed-System Interference Susceptibility Thresholds versus Frequency for Base Station.

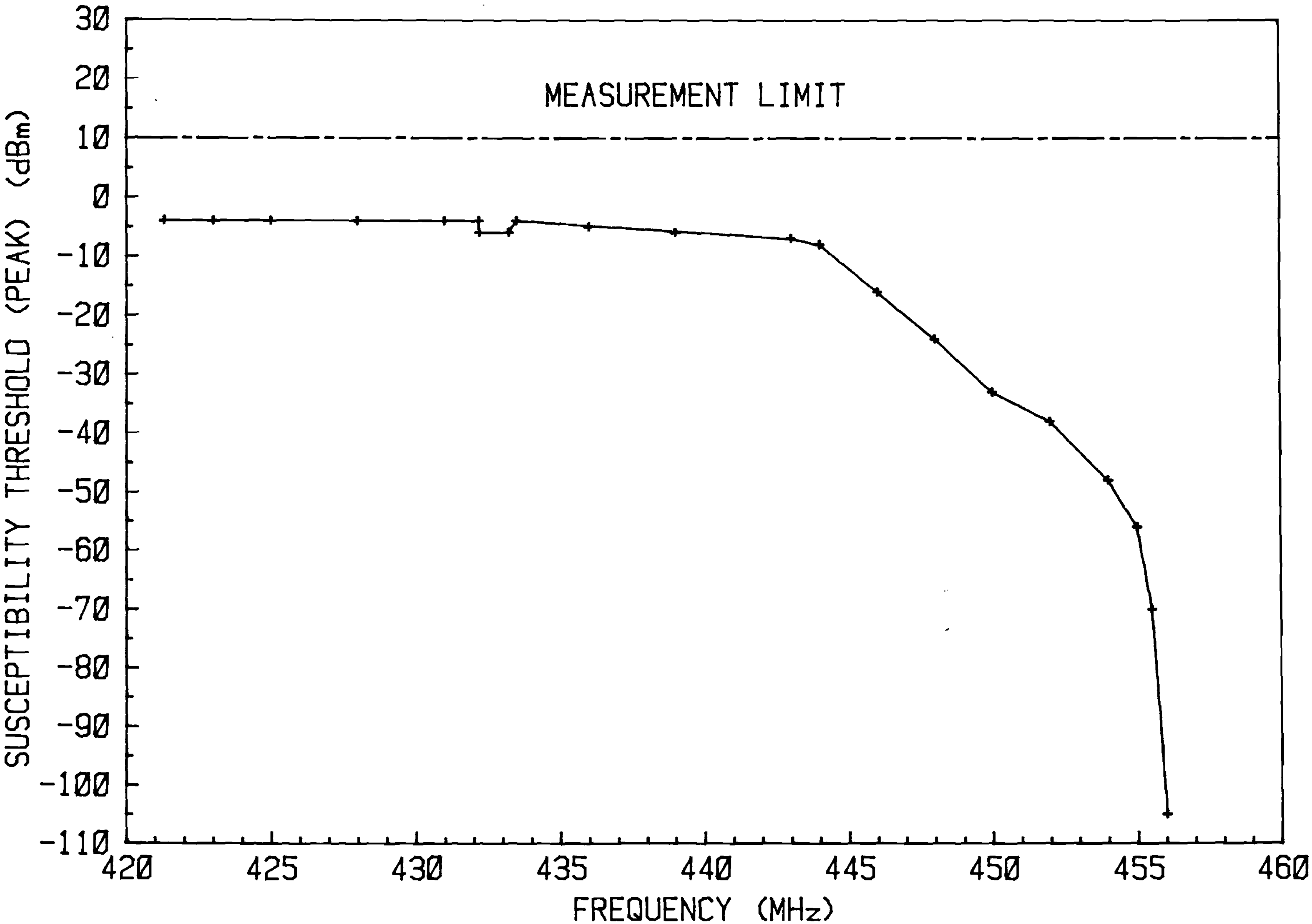


Figure 20. Closed System Interference Susceptibility Threshold versus Frequency for Repeater.

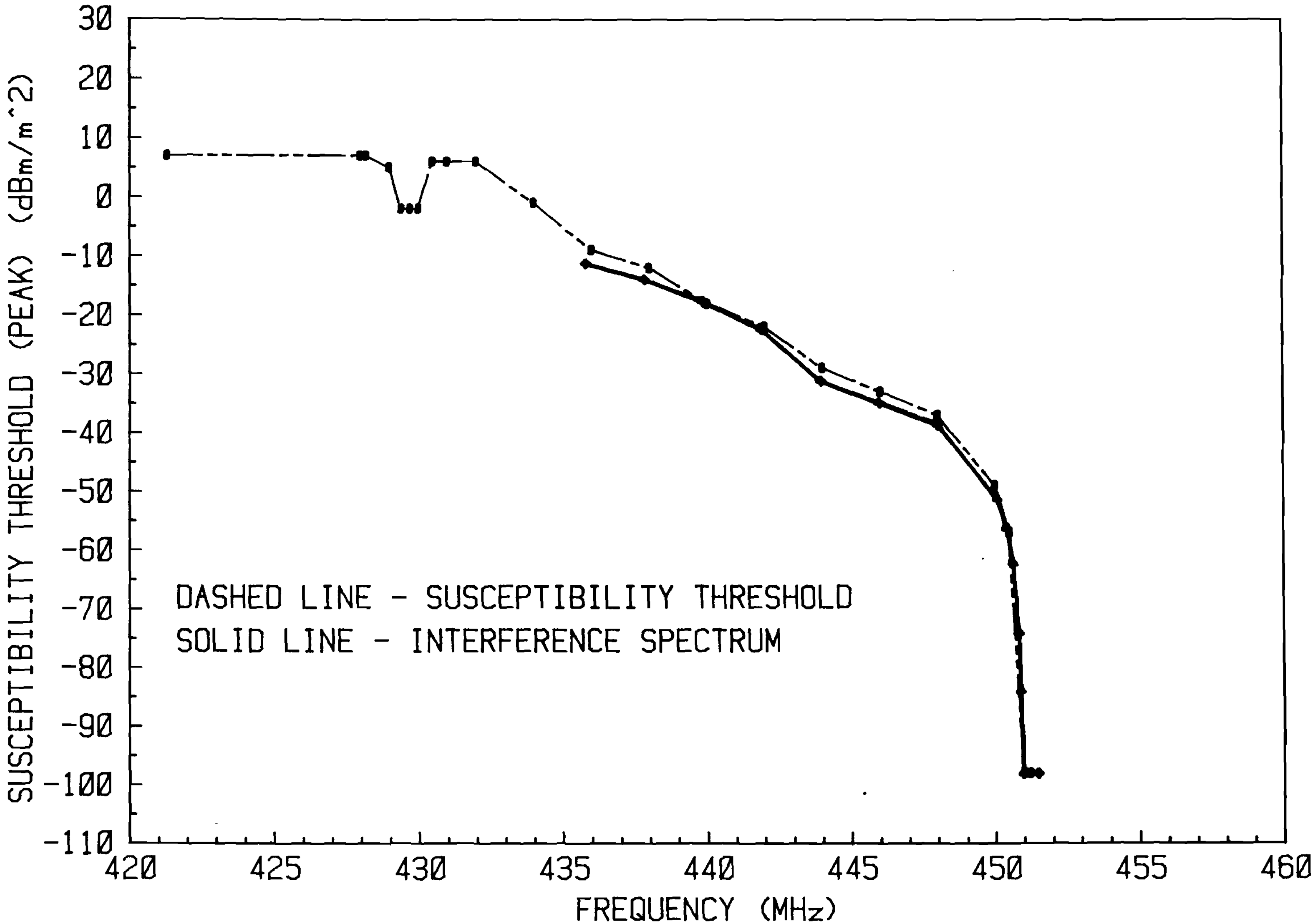


Figure 21. **Comparison of Susceptibility Threshold of SYNTOR Receiver with Inverted Interference Spectrum.**

stated that over some frequency range near the tuned frequency of the UHF receivers, the susceptibility characteristics of the receivers will conform closely to the shape of the interference signal spectrum.

As the center frequency of the interference signal becomes further removed from the receiver tuned frequency, (e.g., 420 - 435 MHz region in Figure 17) the question arises as to the cause of interference (excluding spurious responses). Is the interference caused by the peak power of the pulsed signal or by spectral components which fall within the passband of the receiver? Selected measurements were performed in an attempt to identify which of these interference mechanisms was the cause of interference to the UHF receivers. In these measurements, the closed-system configuration of Figure 6 was used to establish an interference threshold for an interference frequency of 420 MHz. The test configuration was then modified by inserting a tunable bandpass receiver between the hybrid and the receiver. The filter was first tuned to the test specimen receiver frequency (451.2 MHz), which tended to suppress the spectral components of the interference signal near 420 MHz. No significant changes in the interference threshold level was noted.

Next the filter was tuned to 420 MHz, which allowed the main spectral components to be injected into the receiver but suppressed those components at the receiver's tuned frequency. For this arrangement, an increase in the interference signal power was required to reach an interference threshold.

The results of these measurements are an indication that for this particular receiver and interference frequency, the cause of interference is due to spectral components of the interference signal which fall within the receiver passband. However, a firm conclusion that interference to the UHF receivers will always result from this particular interference mechanism cannot be made because of likely variations in receiver characteristics and interference conditions that will exist in a field environment. It may be that in some circumstances, interference may be caused by the peak power injected into the receiver, or by a combination of peak power and spectral components falling within the receiver passband. Furthermore, it is to be recognized that these measurements were performed in a closed-system configuration where the interference signal was injected via the receiver antenna terminals. In an open-system environment, the interference signal may also be coupled into the receiver by other routes (case, power lines, etc.), thus resulting in interference mechanisms which are different from those identified in a closed-system configuration.

Several receiver spurious responses are noted in the data of Figures 17 through 20. For example, the sudden decrease in the susceptibility threshold of Figure 17 near 430 MHz is due to a spurious response in the SYNTOR receiver. This particular spurious response was identified as the 1,1(-) response, or image response, as discussed in Section 2.3.8. The center of this response is at a frequency of 429.8 MHz. The width of the response is approximately 1 MHz due to the 1 MHz chirp width of the interference signal. Spurious response identifications for all of the UHF receivers are given in Section 2.6.

If the test specimen receivers were well shielded, such that interference signals could only be coupled to the receivers via the antenna terminals, then the closed-system susceptibility data recorded would be sufficient to define the susceptibility of the receivers to the PAVE PAWS environment. However, as will be noted later in Section 2.6, the overall susceptibility characteristics of the test specimen receivers changed significantly when the receivers were exposed to an open-system test environment. Thus the closed-system data is useful primarily for reference purposes, and/or for assessing the interference potential of receivers where the antenna is the prime coupling mode for interference (e.g. for the UHF repeater).

The worst-case antenna-conducted susceptibility thresholds for the MICRO, SYNTOR, Base Station, and Repeater receivers are shown in Table II. These worst-case thresholds were taken from the data of Figures 17 through 20 at a frequency of 449.2 MHz.

2.6 Open-System Test Results (UHF Receivers)

The open-system susceptibility data recorded on the UHF receivers are given in Figure 22 through 30. Figures 22 through 24, respectively, show the susceptibility thresholds of the SYNTOR, MICOR, and Base Station receivers

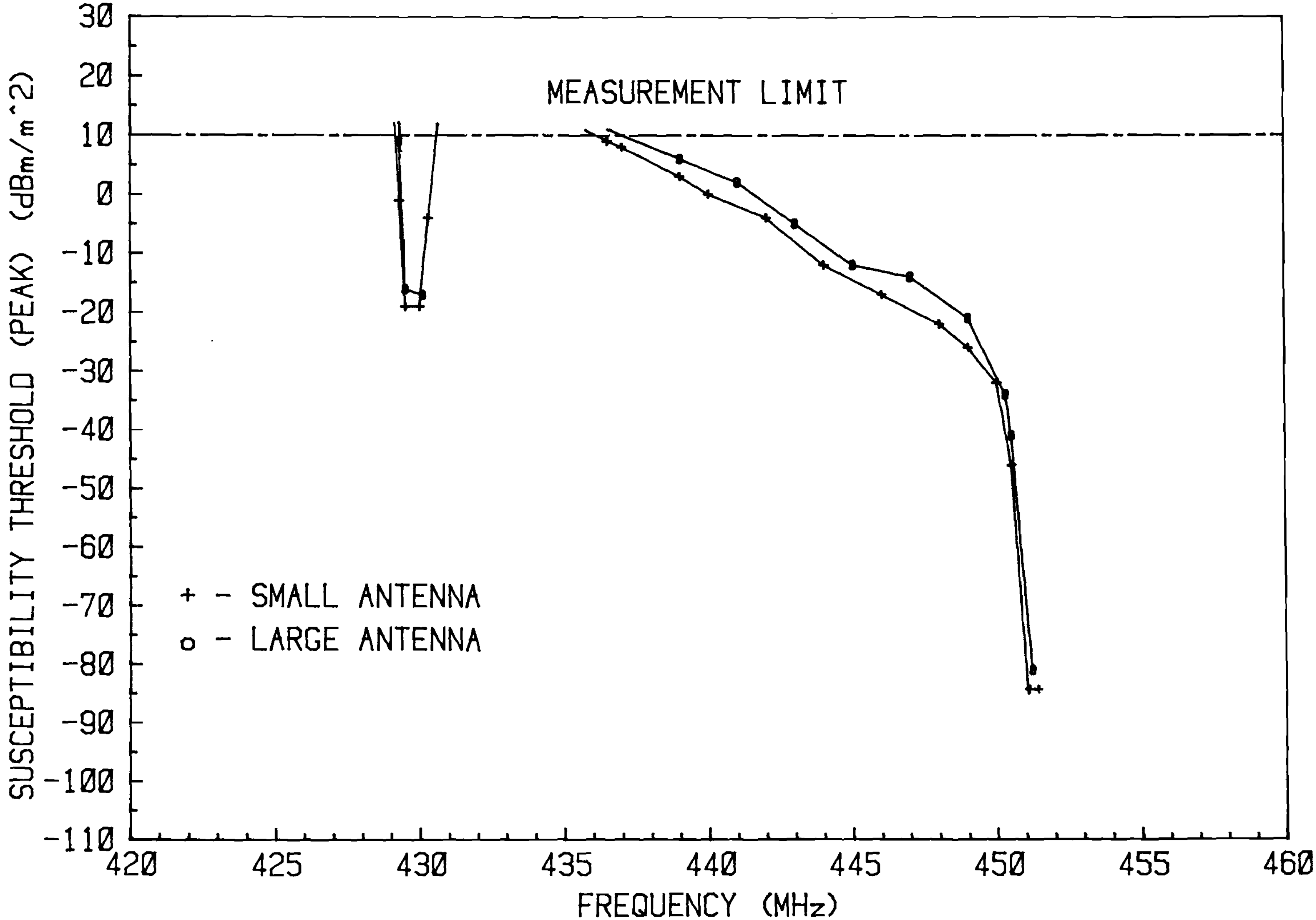


Figure 22. Open-System Interference Susceptibility Threshold versus Frequency for SYNTOR Receiver with Antennas.

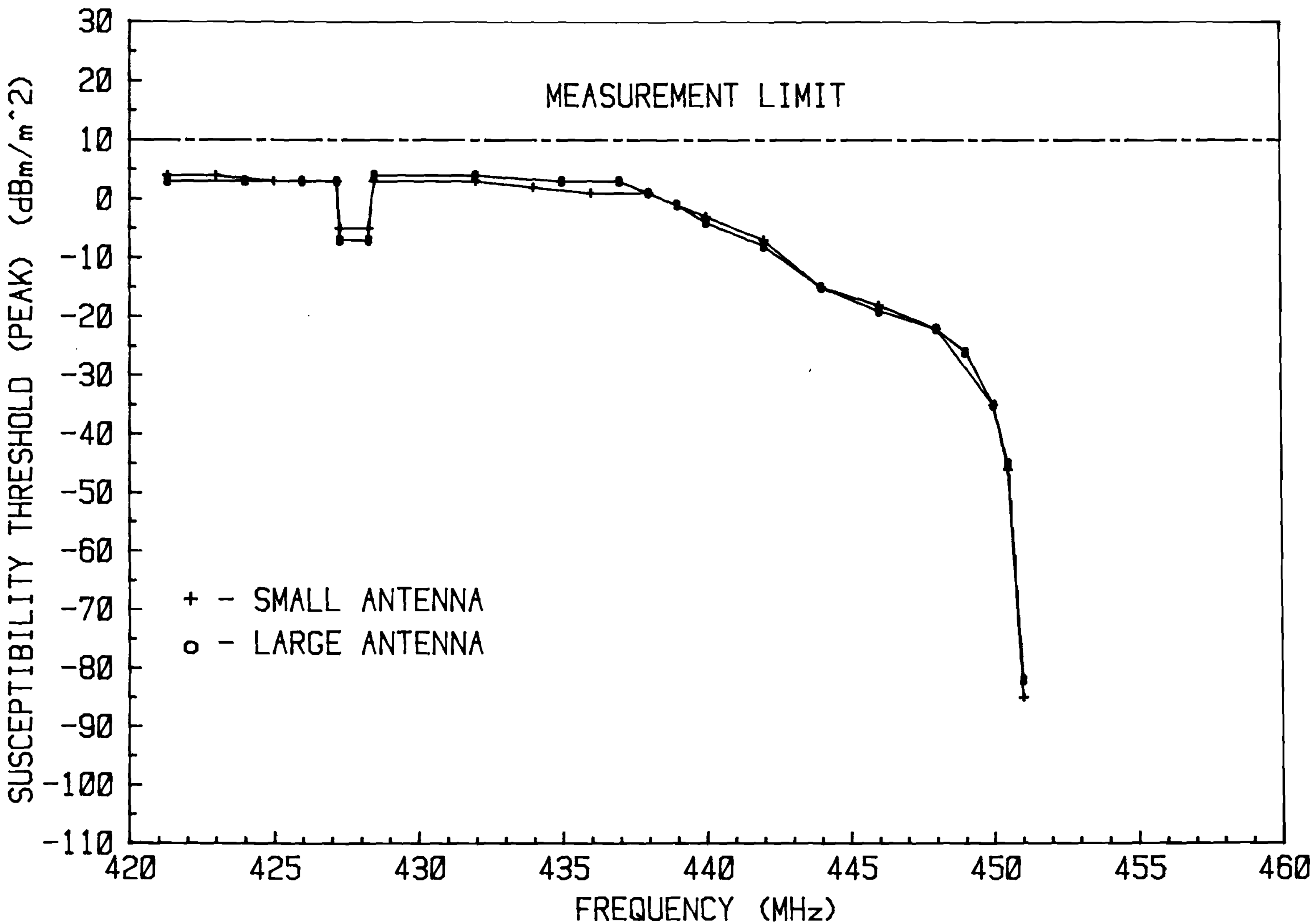


Figure 23. Open-System Interference Susceptibility Threshold versus Frequency for MICOR Receiver with Antennas.

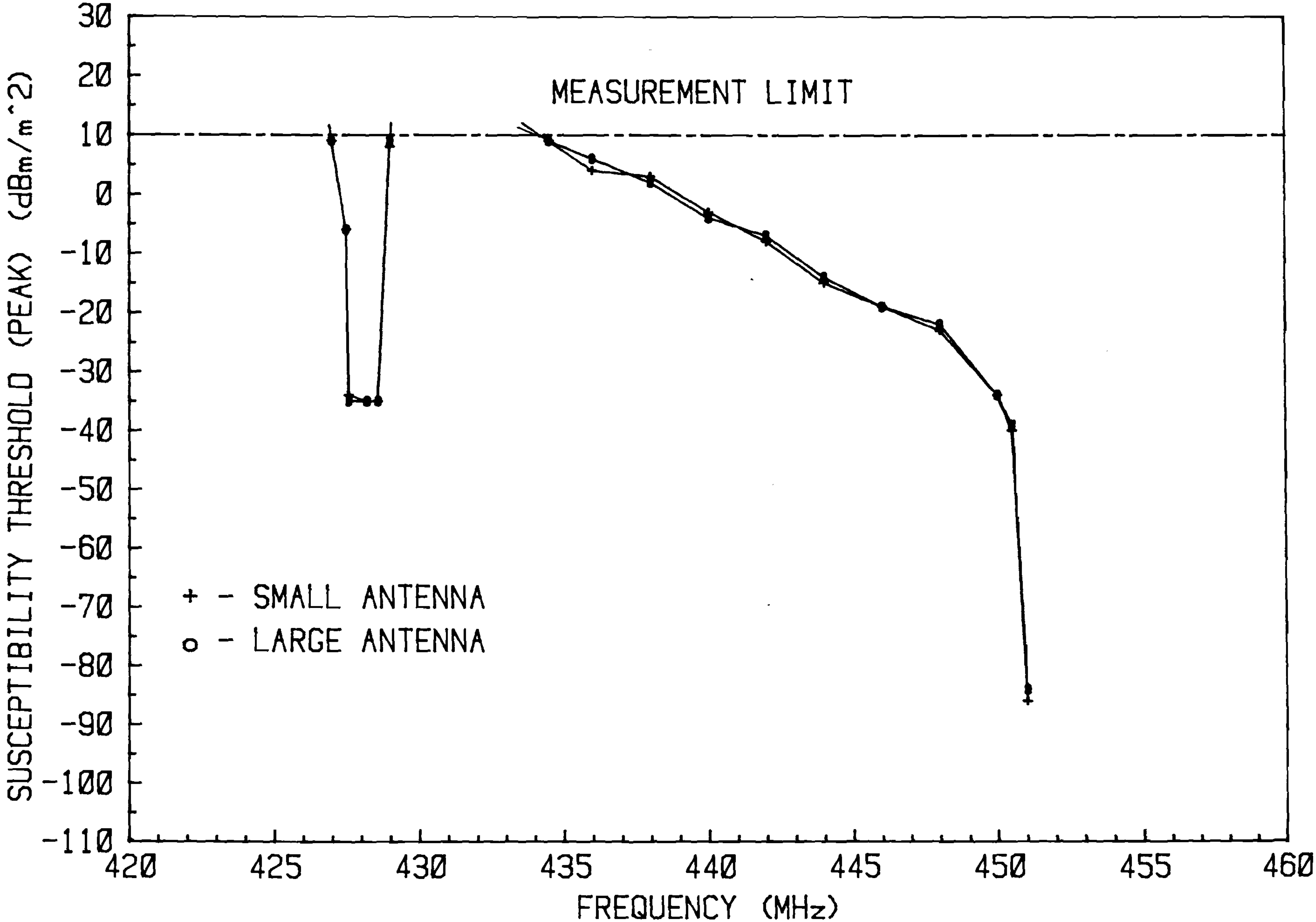


Figure 24. Open-System Interference Susceptibility Threshold versus Frequency for Base Station with Antennas.

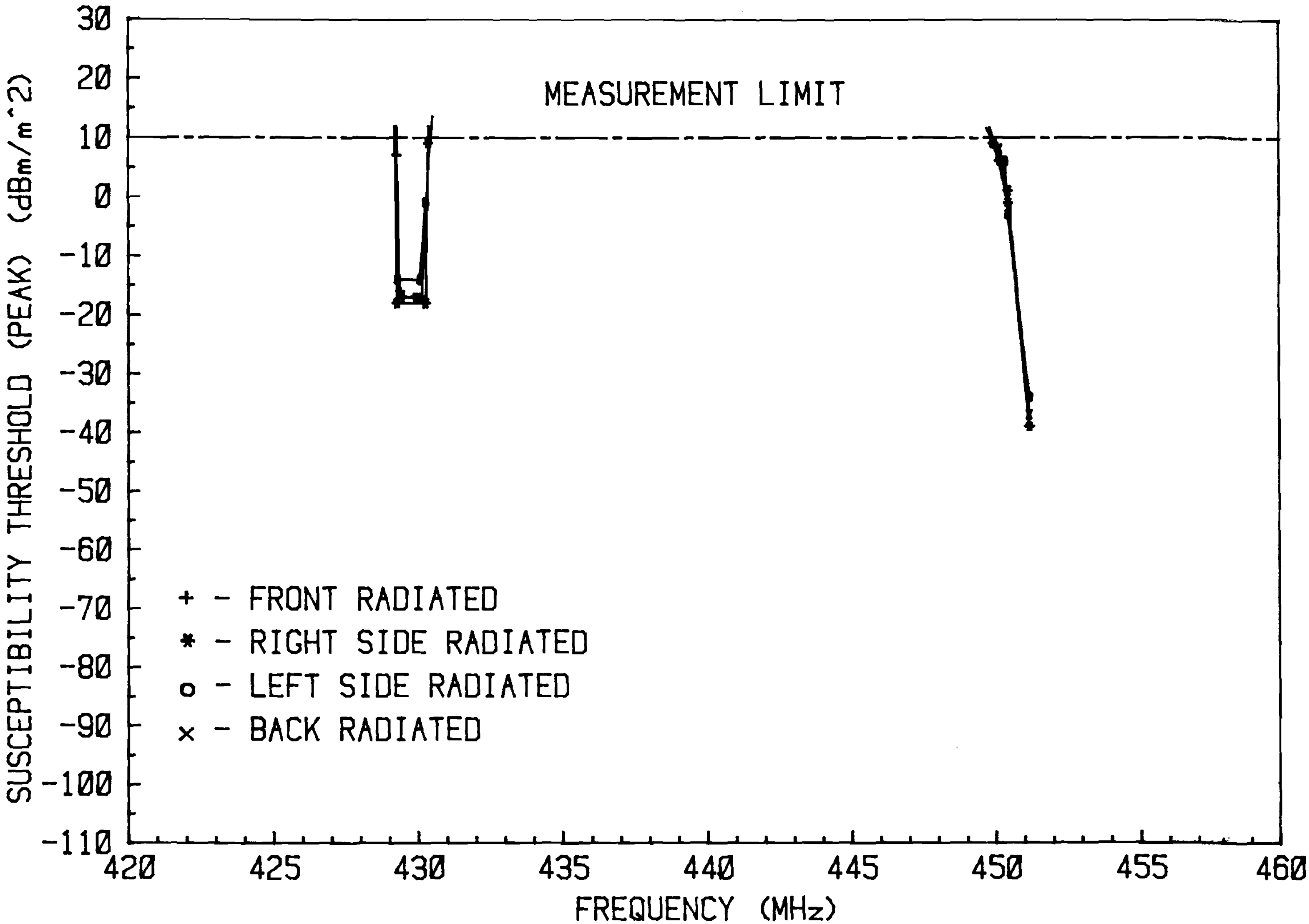


Figure 25. Open-system Interference Susceptibility Threshold versus Frequency for SYNTOR Receiver with no Antenna.

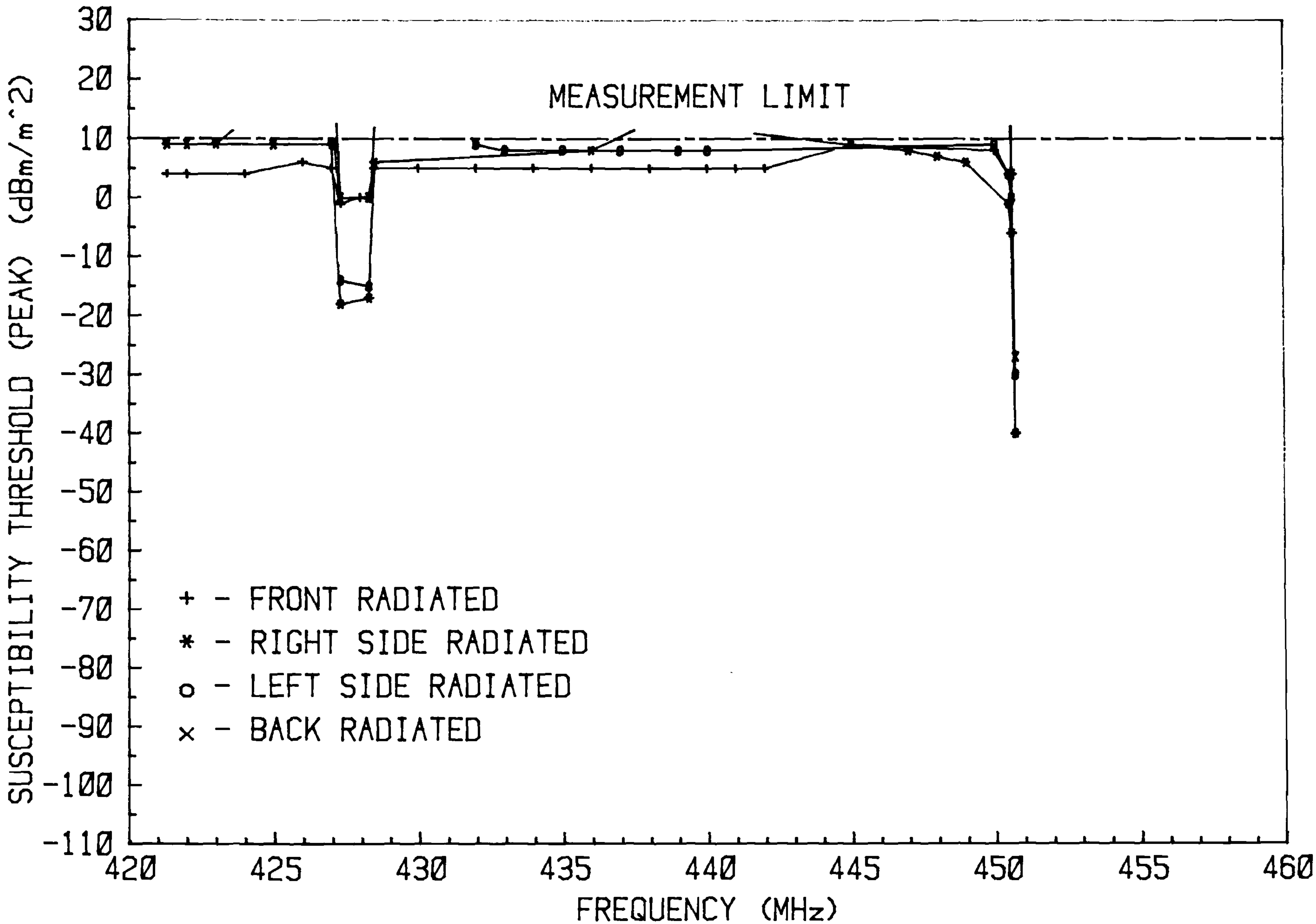


Figure 26. Open-System Interference Susceptibility Threshold versus Frequency for MICOR Receiver with No Antenna.

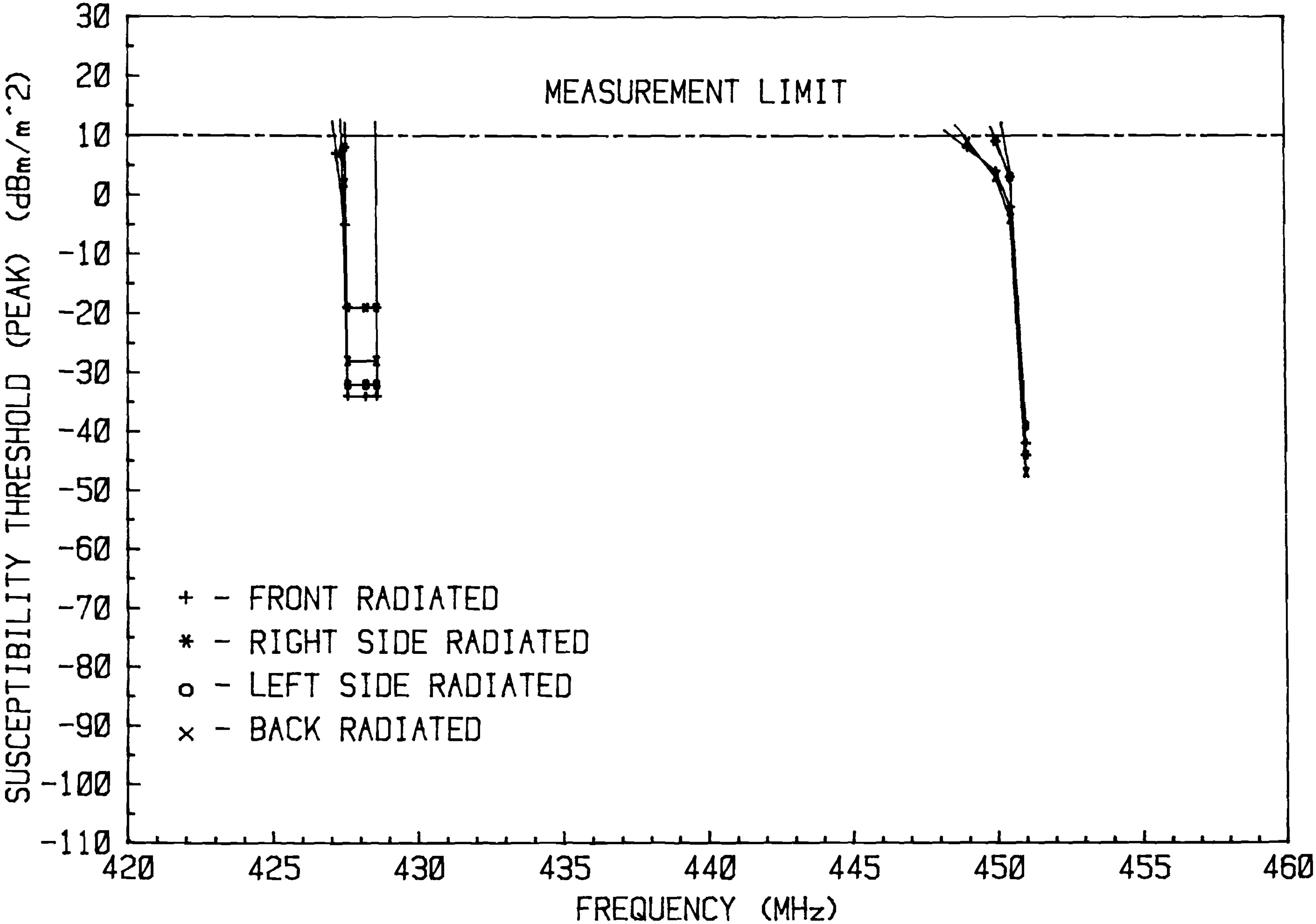


Figure 27. Open-System Interference Susceptibility Threshold versus Frequency for Base Station with No Antenna.

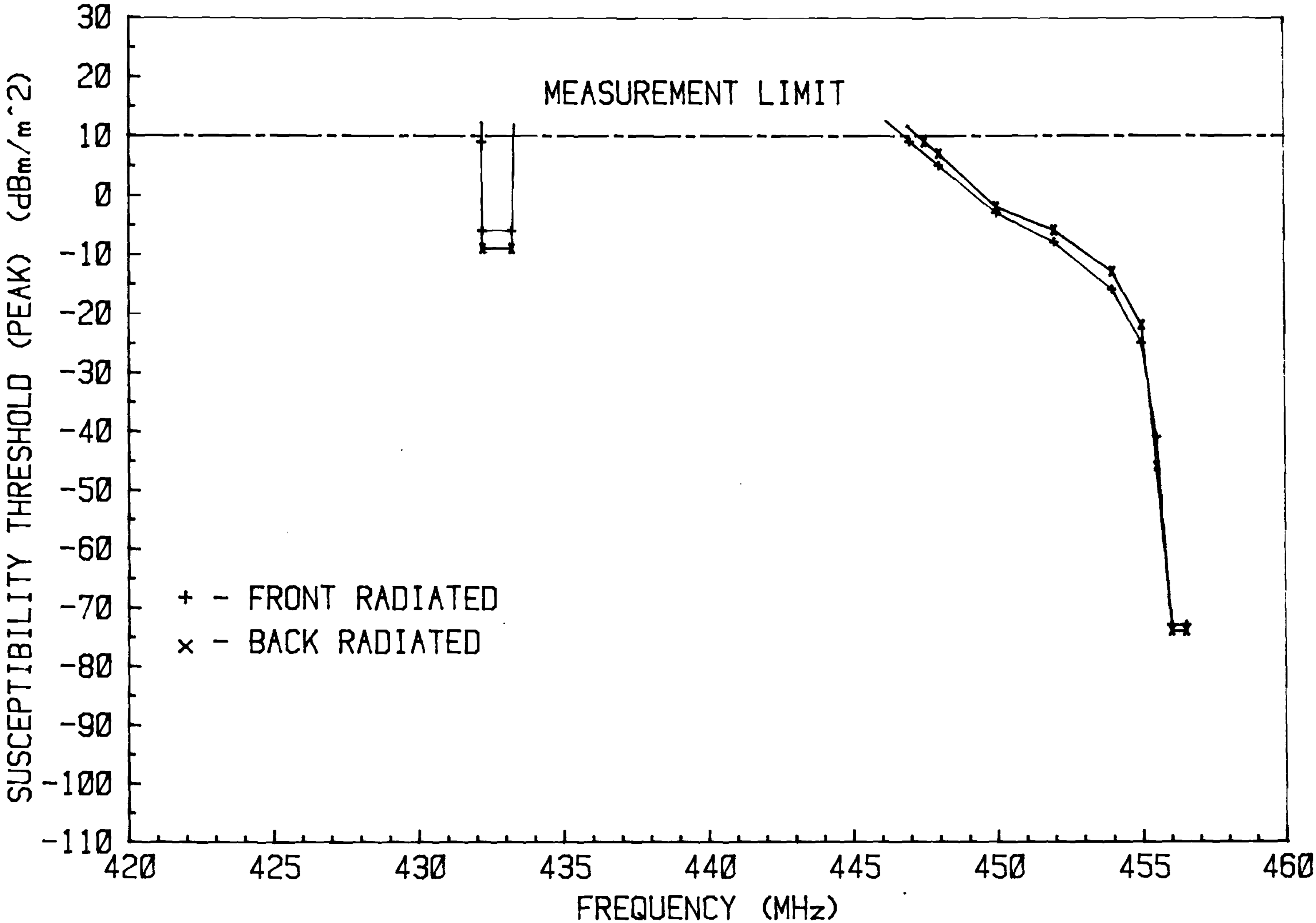


Figure 28. Open-System Interference Susceptibility Threshold versus Frequency for Repeater with No Antenna.

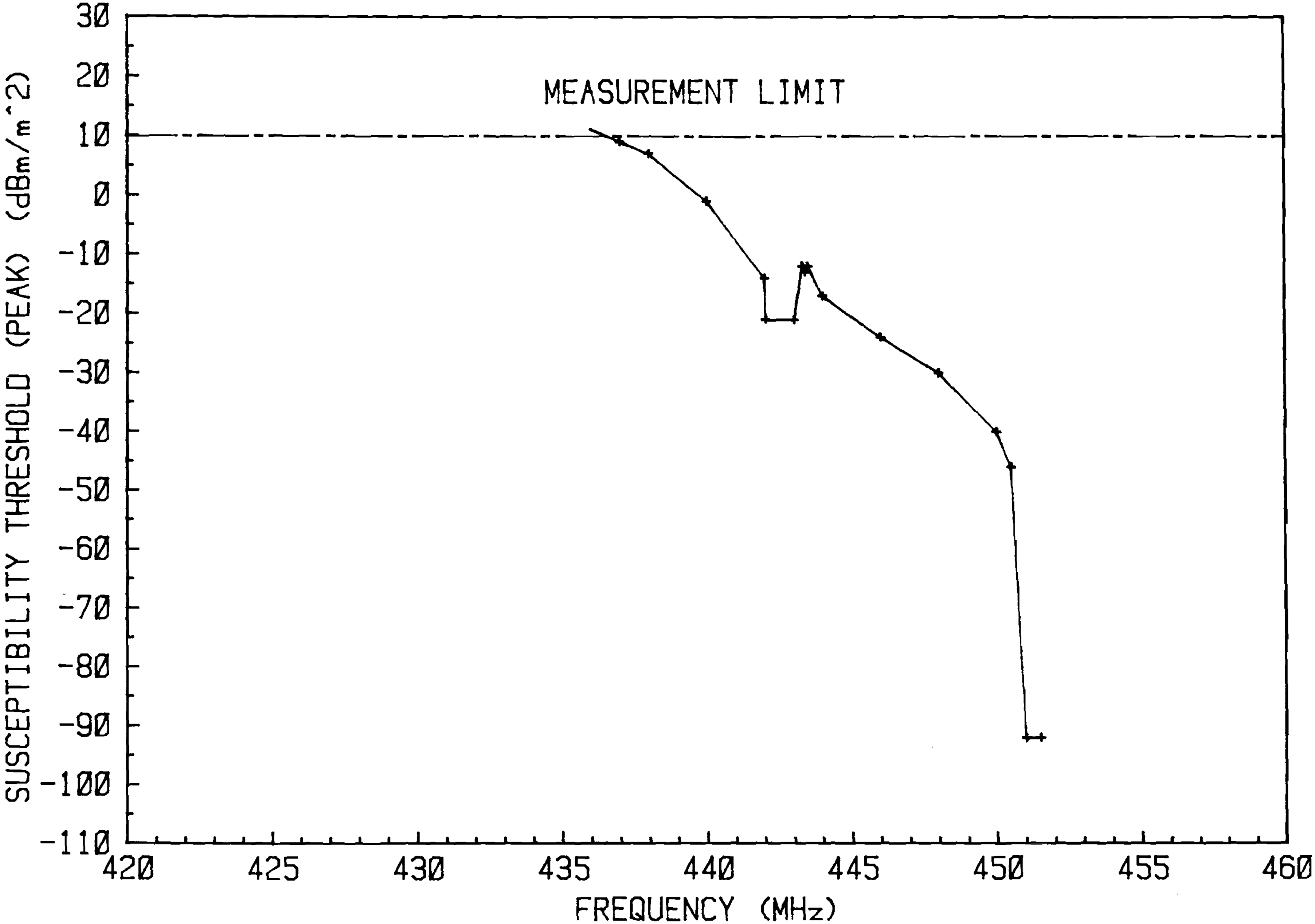


Figure 29. Open-System Interference Susceptibility Threshold versus Frequency for Motorola MT500 Handi-Talkie.

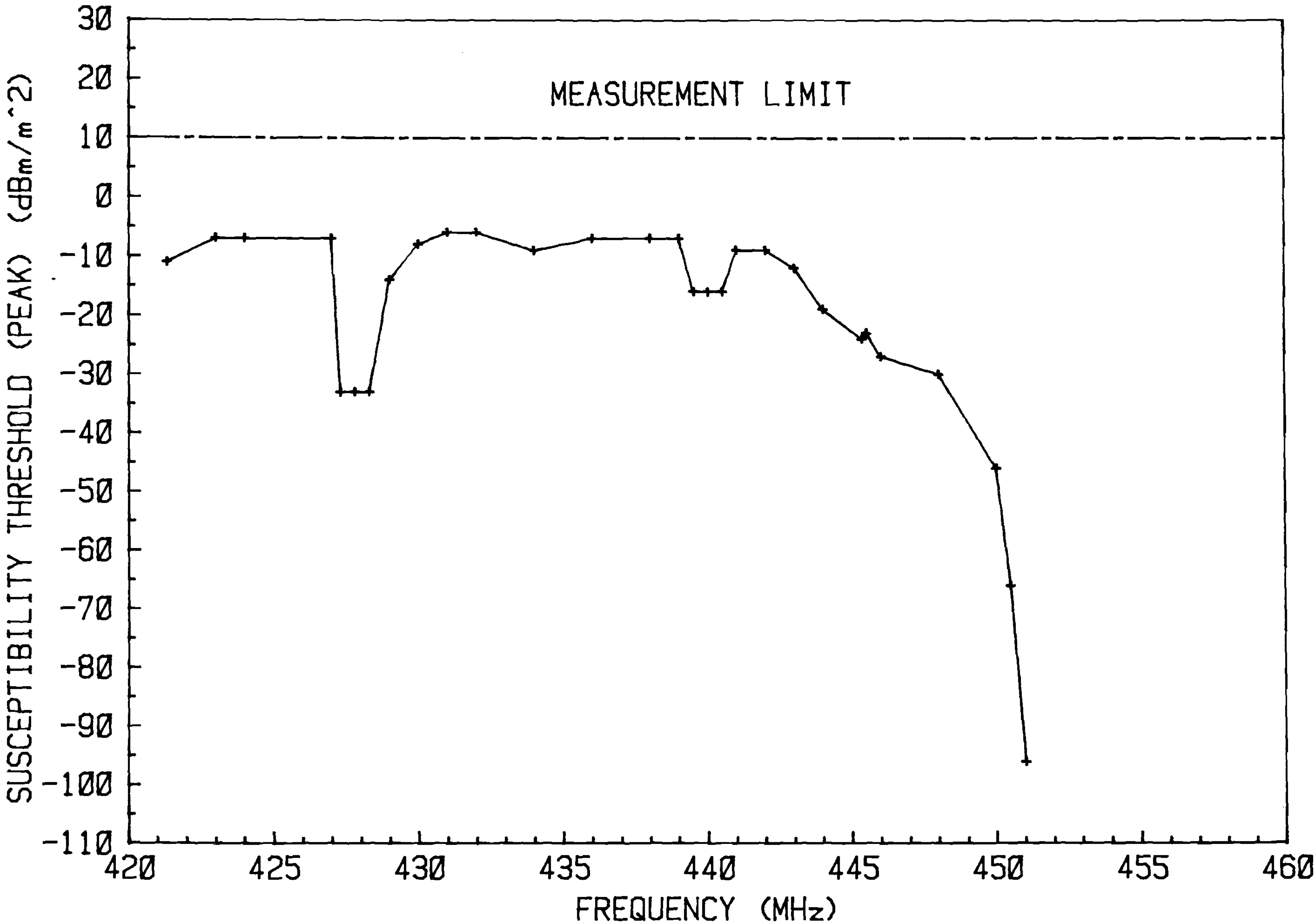


Figure 30. Open-System Interference Susceptibility Threshold versus Frequency for Motorola HT220 Handi-Talkie.

which were recorded when the test specimen antennas were connected to the receivers. Figures 25 through 27 show similar data for the case when the receivers were tested without antennas. The test configuration of Figure 8 was used for these particular interference susceptibility measurements.

Note from Figures 22 through 25 that the open-system susceptibility data (receiver/antenna combination) for the SYNTOR, MICOR, and Base Station receivers exhibit characteristics which are similar to the closed-system data set of Figures 17 through 19. For example, the shapes of the susceptibility curves in the 435 - 450 MHz frequency range are similar, spurious responses occur at given frequencies, etc. These similarities indicate that in the open-system configuration, a large portion of the radiated energy is being coupled to the receiver through the antenna and receiver front-end. On the other hand, note that in the open-system configuration, the receivers are much more susceptible to spurious responses. For instance, the open-system data of Figure 23 show a spurious response in the MICOR receiver at approximately 427.8 MHz, whereas Figure 18 shows that this response did not occur during closed-system measurements. Similar increases in open-system spurious response levels are evident for the SYNTOR and Base Station receivers. Such increases are an indication that at least a portion of the radiated energy is being coupled to the receiver via case radiation.

A measure of the coupling of interference energy via the receiver case is given in Figures 25 through 27. These three figures show the radiated susceptibility characteristics of the SYNTOR, MICOR, and Base Station receivers with no antennas. Note that even with antennas removed, the receivers are still susceptible to the simulated PAVE PAWS signal, even though the overall susceptibility thresholds have increased. The spurious response levels remained essentially unchanged, which indicates that the responses are caused primarily by case-coupling rather than antenna-coupling of the interference signals.

Figure 26 shows that except for a spurious response, the susceptibility threshold of the MICOR receiver remains relatively flat over the 420 - 450 MHz frequency range, at a threshold level near +10 dBm/m^2. This effect is attributed to the peak power of the pulsed signal rather than spectral components of the interference signal which fall at the receiver's tuned frequency.

Figures 28, 29, and 30, respectively, show the open-system susceptibility thresholds recorded on the UHF repeater, the MT500 Handi-Talkie, and the HT220 Handi-Talkie. The test configurations used for the repeater and the Handi-Talkies are shown in Figures 9 and 10, respectively. As mentioned previously, the repeater antenna could not be employed in the tests because of its large size. Thus the data of Figure 28 depicts only the case-radiated susceptibility of the repeater. Since the Handi-Talkies had built-in antennas, the data of Figures 29 and 30 represent the combined antenna conducted/case susceptibility interference characteristics of the two test specimens. Note that the susceptibility characteristics of the repeater and Handi-Talkies exhibit the same trends already noted in the data for the SYNTOR, MICOR, and Base Station Receivers.

All of the receiver spurious responses which were measured were identified following the procedures outlined in Section 2.3.8. These identifications are tabulated in Table III.

The worst-case susceptibility thresholds which were recorded during open-system susceptibility measurements on the test specimen receivers are documented in Table IV. The threshold values were taken from Figures 22 through 30, either at a frequency of 449.2 MHz or at a spurious response frequency. For example, from Figure 23, it can be observed that the worst-case threshold (-30 dBm/m^2) occurred at a frequency of 449.2 MHz. For the Base Station, however, Figure 24 shows that the worst-case threshold of -35 dBm/m^2 occurred at the spurious response frequency of 428 MHz.

The susceptibility data of Figures 22 through 30 and Table IV may be summarized as follows:

(1) The UHF receivers are susceptible to both antenna-conducted and case radiated signals.

TABLE III

UHF RECEIVER SPURIOUS RESPONSES

Test Specimen Receiver	Spurious Response Frequency (MHz)	Identification P, q (sign)
SYNTOR	429.8	1, 1 (-)(1)
MICOR	427.8	1, 1 (-)(1)
Base Station	428.075	1, 1 (-)(1)
Repeater	432.725	1, 1 (-)(1)
MT500 HT	442.525	2, 2 (+)
HT220 HT	427.8	1, 1 (-)(1)
HT220 HT	439.955	(2)

(1) Image Response

(2) Difference between the interference frequency (439.955 MHz) and the first local oscillator frequency (439.5 MHz) falls at the frequncy of the second IF stage (455 kHz).

TABLE IV

WORST-CASE RADIATED SUSCEPTIBILITY
THRESHOLDS FOR UHF RECEIVERS

	Test Specimen Receivers					
	MICRO	SYNTOR	BASE STATION	HT-220	HT-500	REPEATER
Susceptibility Threshold in dBm/m^2 (with antenna)	-30	-28	-35	-39	-35	
Susceptibility Threshold in dBm/m^2 (without antenna)	-18	-18	-34			-9

(2) Interference from the simulated PAVE PAWS signal may be caused by the pick-up of spectral components in the receiver passband, by spurious responses, or by high power effects.

(3) Worst-case interference conditions occur for interference frequencies which are either near the receiver tuned frequency or at receiver spurious response frequencies.

(4) Over the PAVE PAWS frequency range, the worst-case radiated susceptibility threshold for the mobile UHF receivers (SYNTOR, MICOR, Base Station, and Handi-Talkies) is approximately -39 dBm/m^2. This threshold level was determined from Figure 30 at a frequency of 449.2 MHz.

(5) The worst-case radiated susceptibility threshold for the UHF repeater (case-radiated only) is approximately -9 dBm/m^2 (from Figure 28 at 432.7 MHz).

2.7 Open-System Test Results (Microwave Receiver)

2.7.1 General

Radiated susceptibility tests were performed on the microwave equipment using two different test configurations. In one configuration, illustrated in Figure 11, only the receiver was exposed to the radiated interference signal. In the second configuration, shown in Figure 12, both the receiver and the multiplexer were exposed to the interference field.

Five receiver channels were tested in both test configurations. These channels, which were selected based on discussions with Georgia Power Company, are identified in Table V.

The approach followed in performing the tests was to first record susceptibility thresholds as a function of interference frequency using the "standard" interference signal parameters -- PW of 5 ms, PRF of 70 pps, and chirp width of 1 MHz -- and a desired signal level of -32 dBm. Following these

TABLE V

RECEIVER CHANNELS TESTED

Channel	Baseband Frequency (kHz)	BCD Switches 53	52	51	Test Tone (kHz)
G1	4-8	2	2	3	5
1-5-12	60-64	2	4	0	63
5-2-1	1248-1252	5	3	7	1251
8-1-1	2040-2044	7	3	5	2043
10-1-1	2536-2540	8	5	9	2539

measurements, the effects of PW, PRF, chirp width, and desired signal level were measured at selected interference frequencies. Susceptibility thresholds were then modified to reflect the effects of these parameters. This approach was used (rather than recording parameter effects first) because preliminary checks revealed that the effects of some of these test parameters were dependent upon interference frequency.

2.7.2 Receiver Alone Tests

2.7.2.1 Susceptibility Versus Frequency

With only the receiver exposed to the interference field, no interference to the data stream was noted. Also, over the total 420 - 450 MHz interference frequency range, audio interference was recorded only on the lower two test channels. The remaining three channels were susceptible to audio interference only at discrete frequencies within this band.

Figures 31 and 32, respectively, show the audio susceptibility thresholds recorded as a function of frequency for the 4 - 8 kHz and 60 - 64 kHz channels. As expected, these data exhibit characteristics which are typical of high power interference in that they generally show no unique dependence on the frequency of the interference signal. The receiver components and circuitry are simply responding to the peak power contained in the pulse waveform. However, note in both figures that for an interference frequency near 421 MHz, a sharp decrease in the susceptibility threshold occurs. This data trend is indicative of frequency dependent interference, although its cause was not determined.

For the other three receiver channels, audio interference was noted only at discrete frequencies. Table VI lists these frequencies and the threshold levels recorded. The fact that interference occurred only at these discrete frequencies indicates a frequency dependent interference problem although the cause is not known.

The worst-case audio threshold recorded on the five receiver channels was approximately -20 dBm. This level was determined from Figure 32 (Channel 1-5-12) at a frequency of 420.8 MHz.

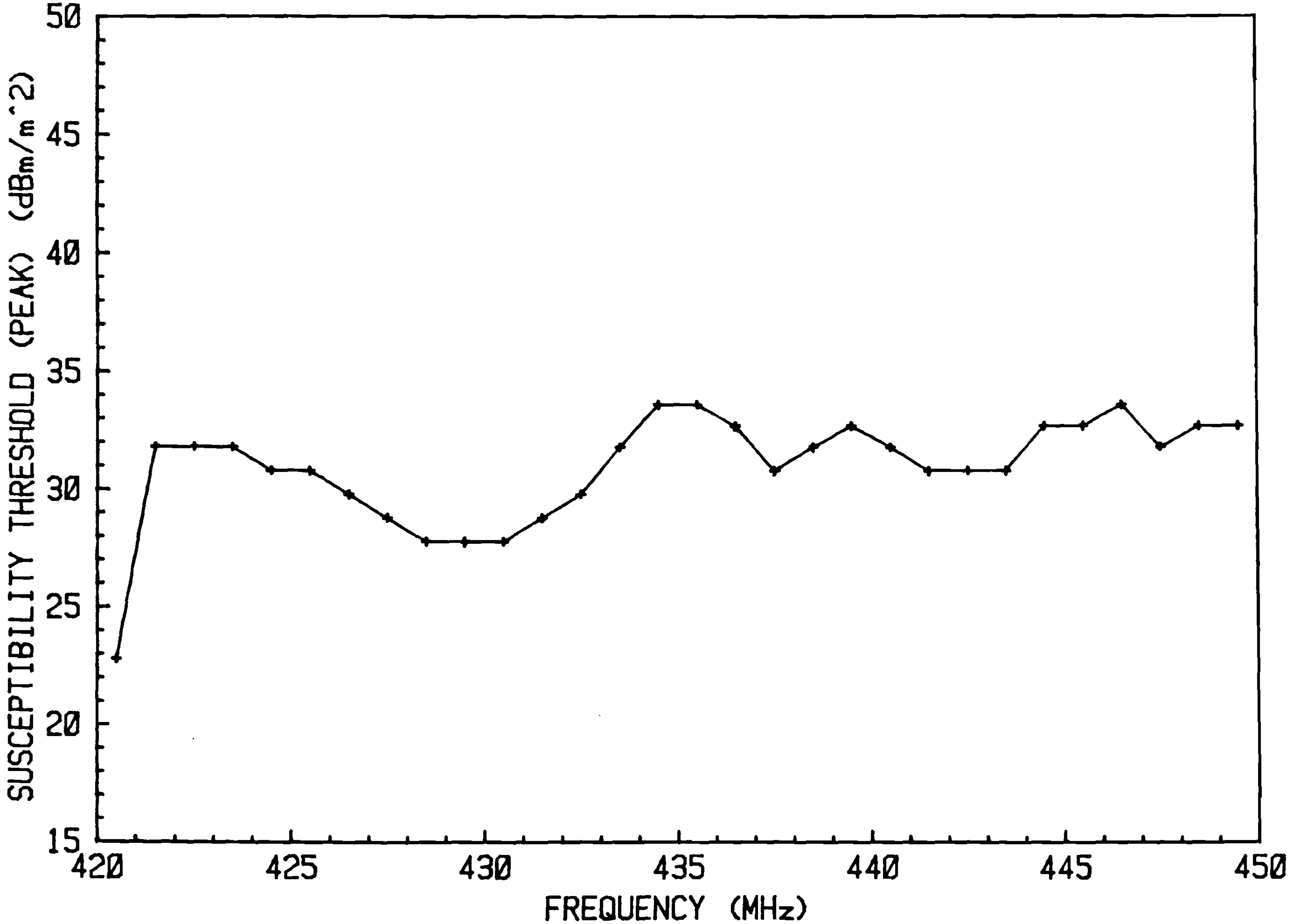


Figure 31. Radiated Susceptibility Thresholds versus Frequency for Receiver Alone -- Channel G1 (4 - 8 kHz).

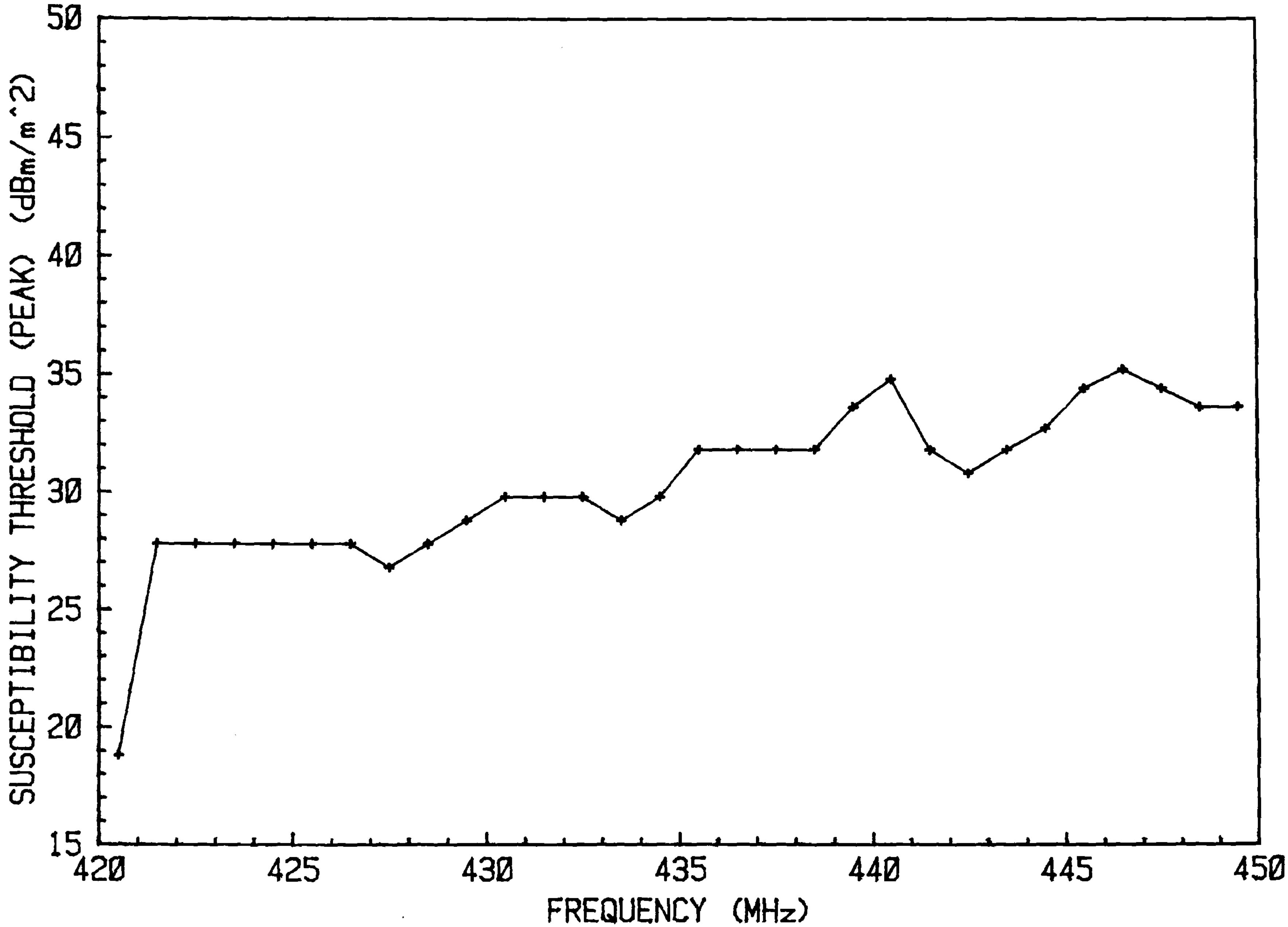


Figure 32. Radiated Susceptibility Thresholds versus Frequency for Receiver Alone -- Channel 1-5-12 (60 - 64 kHz).

TABLE VI

SUSCEPTIBILITY THRESHOLDS RECORDED ON
CHANNELS 5-2-1, 8-1-1, and 10-1-1

Channel	Susceptible Frequencies (MHz)	Audio Threshold Level (dBm/m^2)
5-2-1	421.50	25.8
	434.75	26.8
8-1-1	422.32	23.8
	433.65	27.8
10-1-1	422.80	22.8
	433.49	27.8

2.7.2.2 Effects of Desired Signal Level

The effects of desired signal level on susceptibility thresholds were measured by varying the desired signal level from -32 dBm to a value which activated receiver squelch. The interference frequencies employed for each test channel are listed in Table VII. Figure 33 shows the results of these measurements for the five receiver channels. Note that while the results were not consistent from channel to channel, a decrease in desired signal level was generally accompanied by an increase in the field intensity required to cause interference for all channels. Minimum thresholds occurred at the -32 dBm level of signal input.

2.7.2.3 Effects of PW, PRF, and Chirp Width

The effects of pulse width on audio susceptibility thresholds for the five test channels are given in Figure 34. These data were recorded at a PRF of 25 pps (to accommodate duty cycle variations), a chirp width of 1 MHz, and at the interference frequencies given in Table VII. Note from this figure that minimum thresholds on each test channel occurred for the maximum pulse width setting of 15 ms.

The measured effects of pulse repetition frequency on audio susceptibility thresholds for each of the five test channels are documented in Appendix A. These tests were performed using two pulse widths (1 ms and 5 ms), a chirp width of 1 MHz, and the test frequencies identified in Table VII. Typical results obtained are shown in Figure 35, which depicts PRF effects recorded on Channel 1-5-12 (60 - 64 kHz). Note from this figure that, except for the lower PRF's, the susceptibility thresholds are relatively constant with respect to pulse repetition frequency. At PRF's in the 5 - 25 pps range, threshold variations approaching 5 dB were noted for some test channels.

Variations in chirp width did not generally affect the susceptibility of the microwave receiver. The primary effect noted was on the upper three channels, which were susceptible at discrete frequencies. For these three channels, the frequency range over which thresholds could be recorded varied in direct proportion to chirp width.

TABLE VII

INTERFERENCE FREQUENCY EMPLOYED IN
DESIRED SIGNAL TESTS

Channel	Interference Frequency (MHz)
61	420.50
1-5-12	420.50
5-2-1	421.50
8-1-1	422.32
10-1-1	422.80

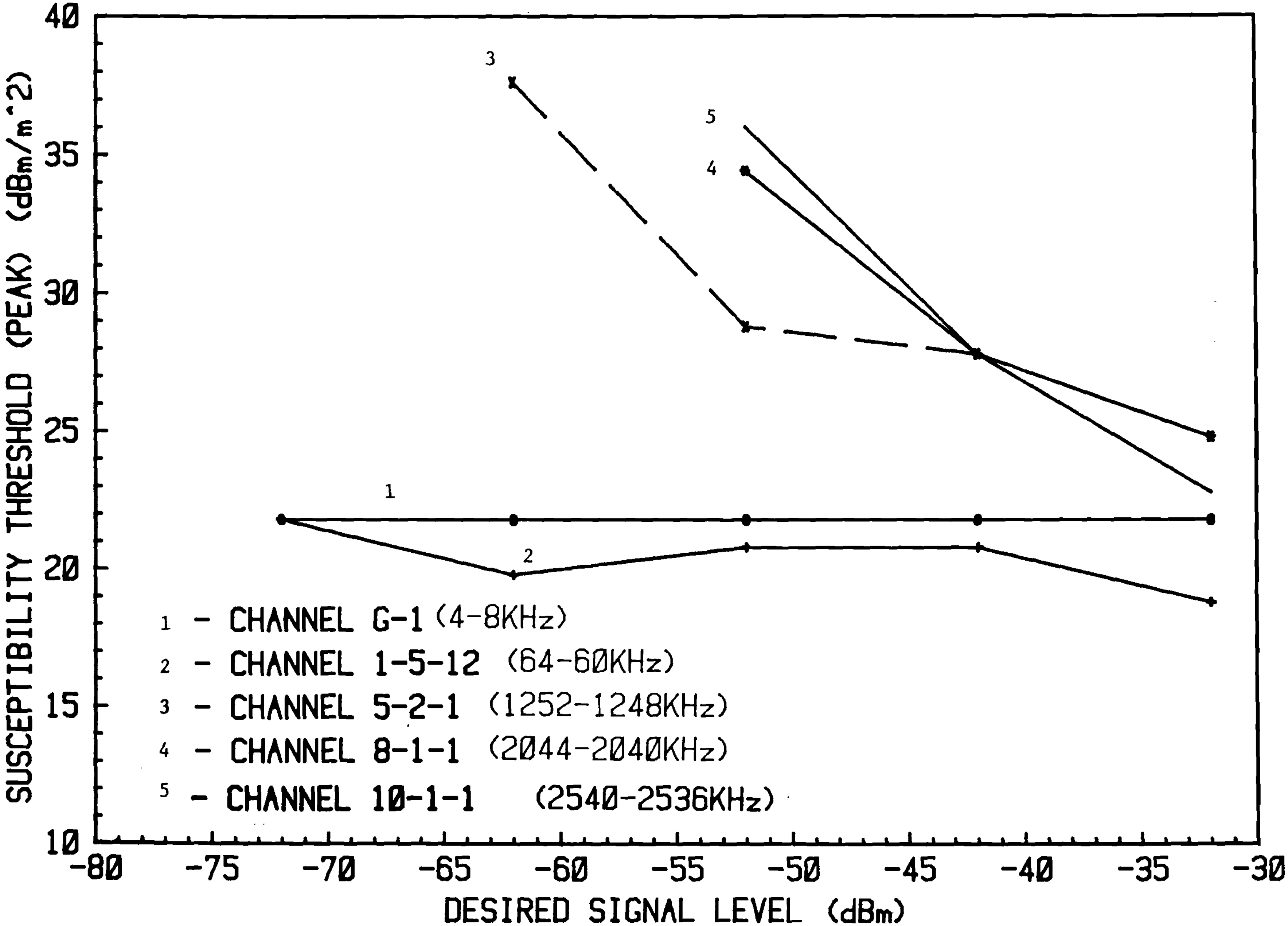


Figure 33. Effects of Desired Signal Level on Susceptibility Thresholds -- Receiver Alone Tests.

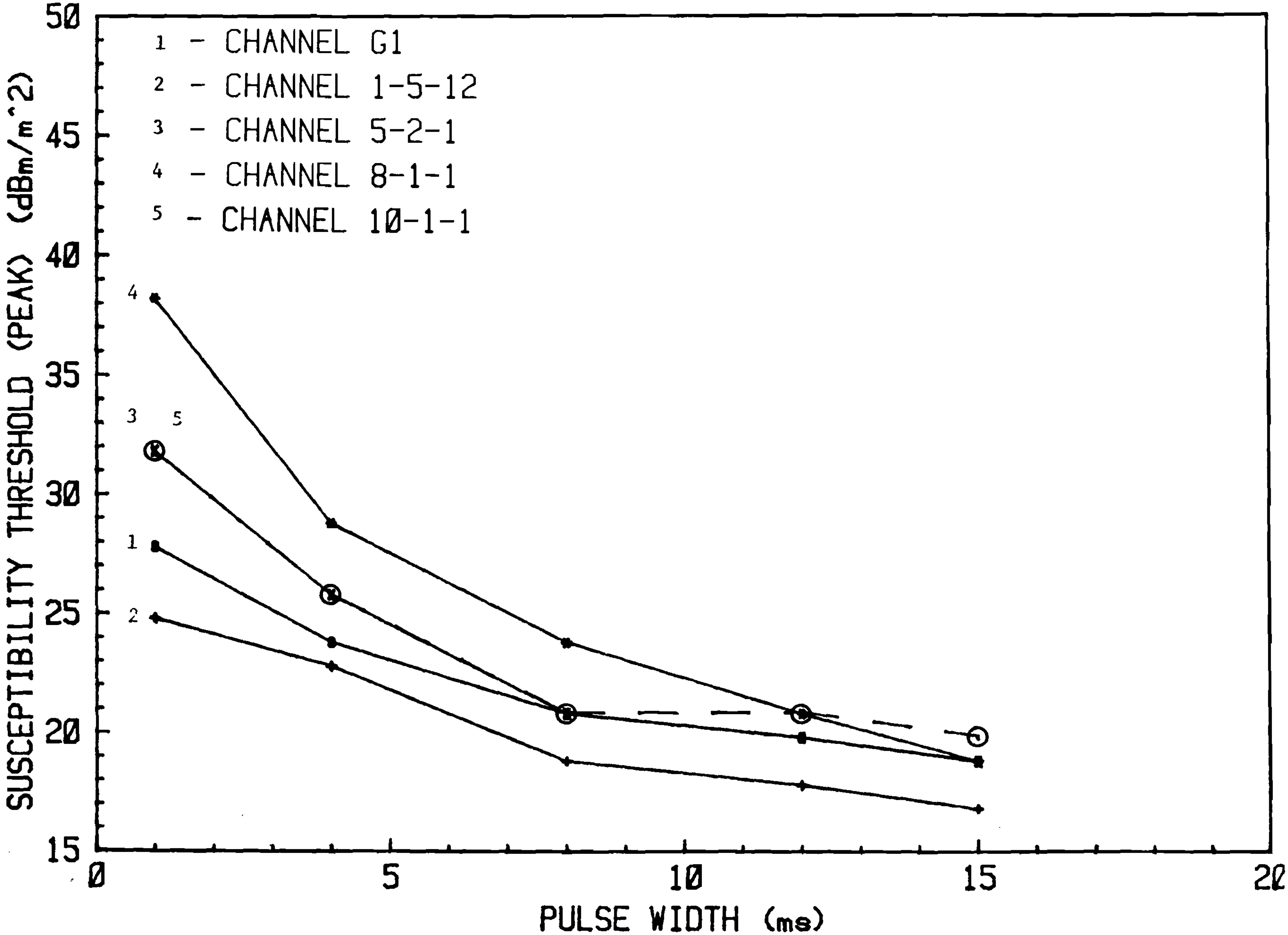


Figure 34. Radiated Susceptibility Thresholds versus Pulse Width for Receiver Alone.

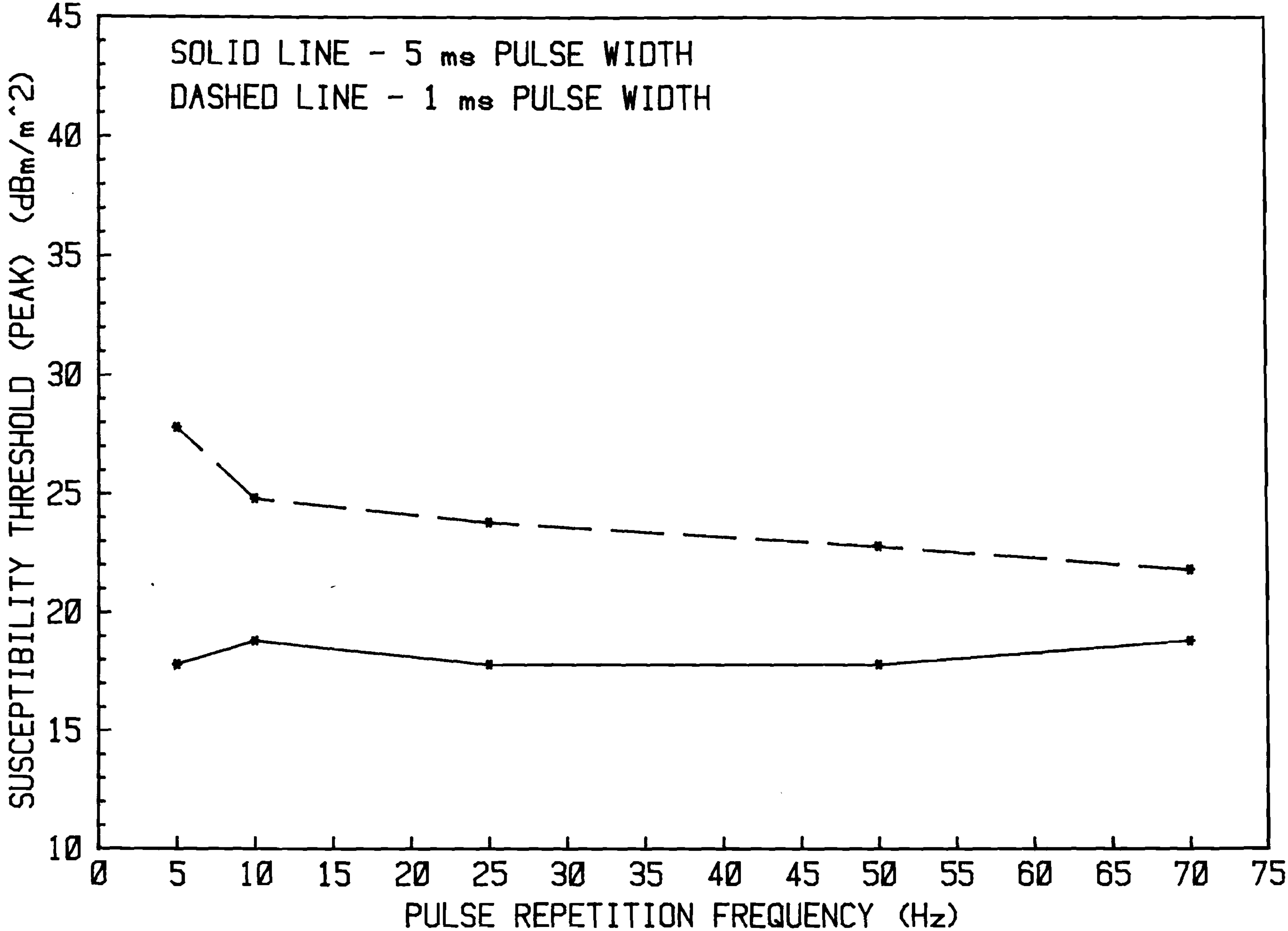


Figure 35. Radiated Susceptibility Thresholds versus Pulse Repetition Frequency for Receiver Alone -- Channel 1-5-12 (60 - 64 kHz).

2.7.3 Receiver/Multiplexer Tests

2.7.3.1 Susceptibility Versus Frequency

In the receiver/multiplexer test configuration of Figure 12, both audio and data interference were noted on all five test channels over the 420 - 450 MHz test frequency range. The data recorded during these tests is contained in Appendix B. An illustrative example of these data, which shows the audio and data susceptibility thresholds as a function of interference frequency for Channel 1-5-12, is given in Figure 36. Note from this figure that both audio and data interference occurred over the total test frequency range, the minimum interference thresholds occurred at lower interference frequencies, and the audio susceptibility threshold is considerably lower than the data susceptibility threshold. These characteristics were evident in the data recorded on the other four test channels. The minimum audio threshold recorded was +6 dBm/m^2, and the minimum data threshold recorded was +18 dBm/m^2.

2.7.3.2 Effects of Desired Signal Level

The effects of desired signal level on susceptibility thresholds were measured by varying the desired signal level from -32 dBm to a value which activated receiver squelch. The interference frequency was set to 420.5 MHz for these tests. The results obtained for the five receiver channels revealed that data thresholds remained essentially unchanged when the desired signal input level was varied. However, Figure 37 shows that audio threshold variations as a function of desired signal level were similar to those obtained in the receiver alone tests. Note that with the exception of Channel G1, minimum thresholds are obtained for a signal input of -32 dBm, and that the thresholds remain constant or increase as the desired signal level decreases.

2.7.3.3 Effects of PW, PRF, and Chirp Width

Measurements of pulse width effects on audio and data susceptibility thresholds were performed on all five test channels using a PRF of 25 pps, a chirp width of 1 MHz, and an interference frequency of 420.5 MHz. The results

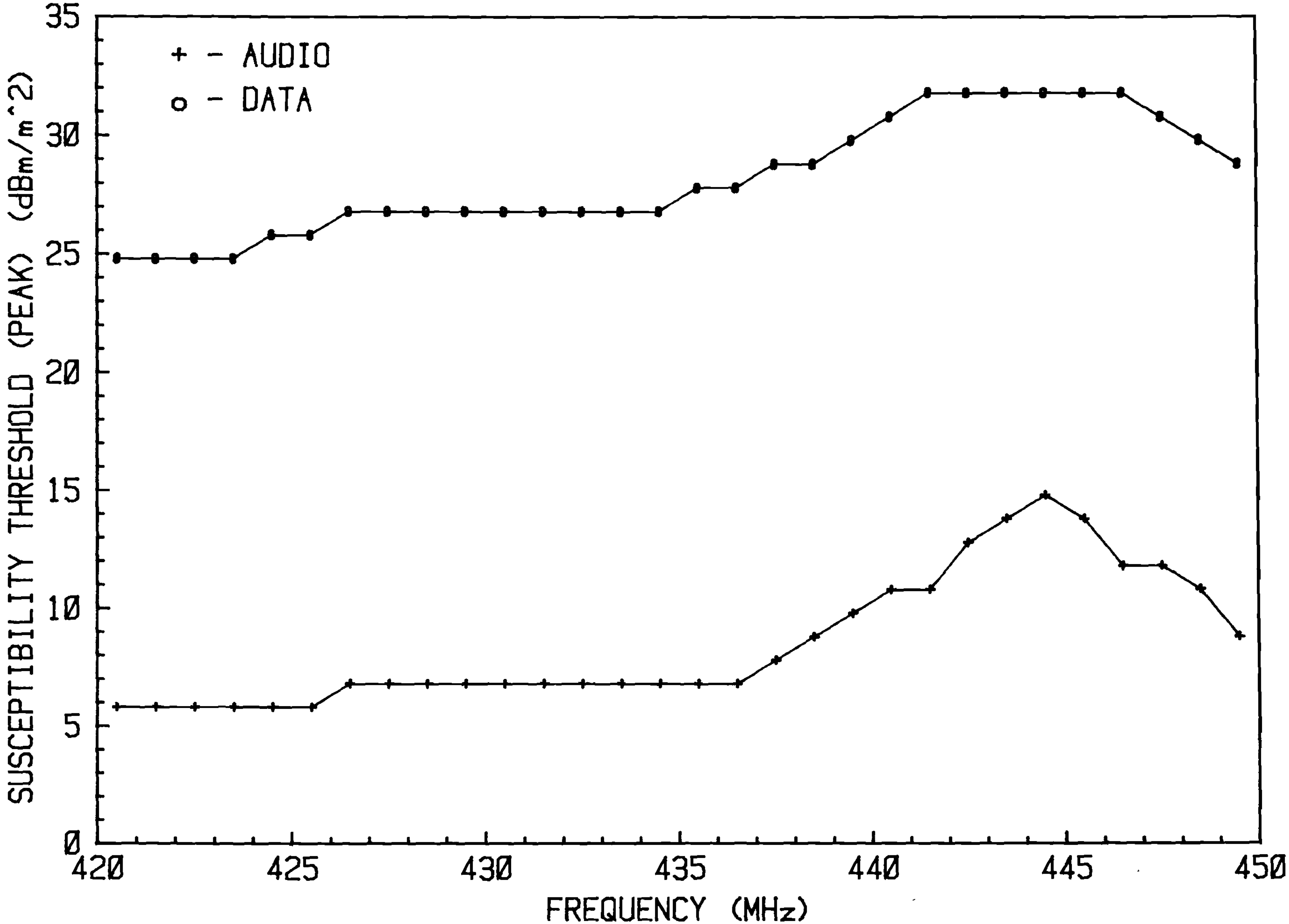


Figure 36. Radiated Susceptibility Thresholds versus Frequency for Receiver/Multiplexer -- Channel 1-5-12 (60 - 64 kHz).

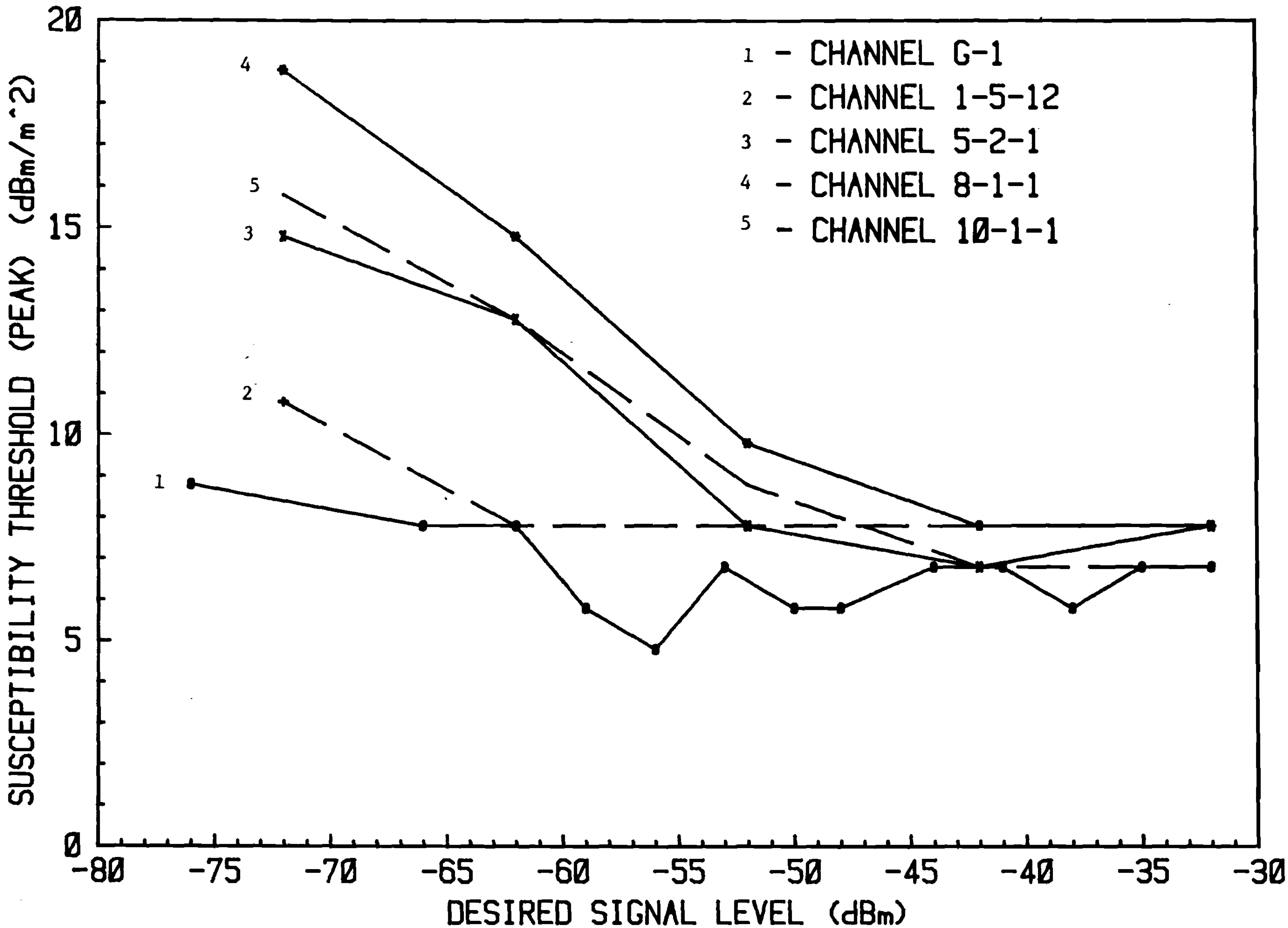


Figure 37. Effects of Desired Signal Level on Susceptibility Thresholds -- Receiver/Multiplexer Tests.

of these measurements showed that pulse width variations from 1 - 15 ms had no significant effect on either the audio or data thresholds.

The measured effects of pulse repetition frequency on audio and data susceptibility thresholds for each of the five test channels are given in Appendix C. These tests were performed using two pulse widths (1 ms and 5 ms), a 1 MHz chirp width, and an interference frequency of 420.5 MHz. Typical results of these tests are shown in Figure 38, which illustrates PRF effects recorded on Channel 1-5-12 (60 - 64 kHz). Note from this figure that both audio and data thresholds remain relatively constant for PRF's ranging from approximately 25 to 70 pps. As the PRF is decreased below 25 pps, both the audio and data thresholds begin to show significant decreases. The amount of decrease is generally more pronounced for the 5 ms pulse width data than for the 1 ms pulse width data.

The data recorded on the other four channels exhibit characteristics similar to those depicted in the data of Figure 38. The lowest audio threshold recorded was -4 dBm/m^2, which occurred on Channel 1-5-12 at a PRF of 5 pps. The lowest data threshold recorded was +7 dBm/m^2, which occurred on Channel G1 at a PRF of 5 pps.

Checks of chirp width effects did not reveal any variations in audio or data susceptibility thresholds as a function of chirp width.

2.7.4 Threshold Adjustments to Reflect PW and PRF Effectss

Measurements of susceptibility thresholds versus frequency were performed using a "standard" interference signal PW, PRF, and chirp width of 5 ms, 70 pps, and 1 MHz, respectively. In order to establish worst-case susceptibility thresholds for the receiver and receiver/multiplexer, it is necessary to "adjust" the threshold levels obtained with the standard test parameters to reflect the effects of pulse width and pulse repetition frequency. These adjustments were made by observing the effects of PW and PRF and, where appropriate, decreasing the susceptibility thresholds to reflect these effects. The adjustments were made based on overall trends observed in all of the data. No attempt was made to adjust the threshold data for

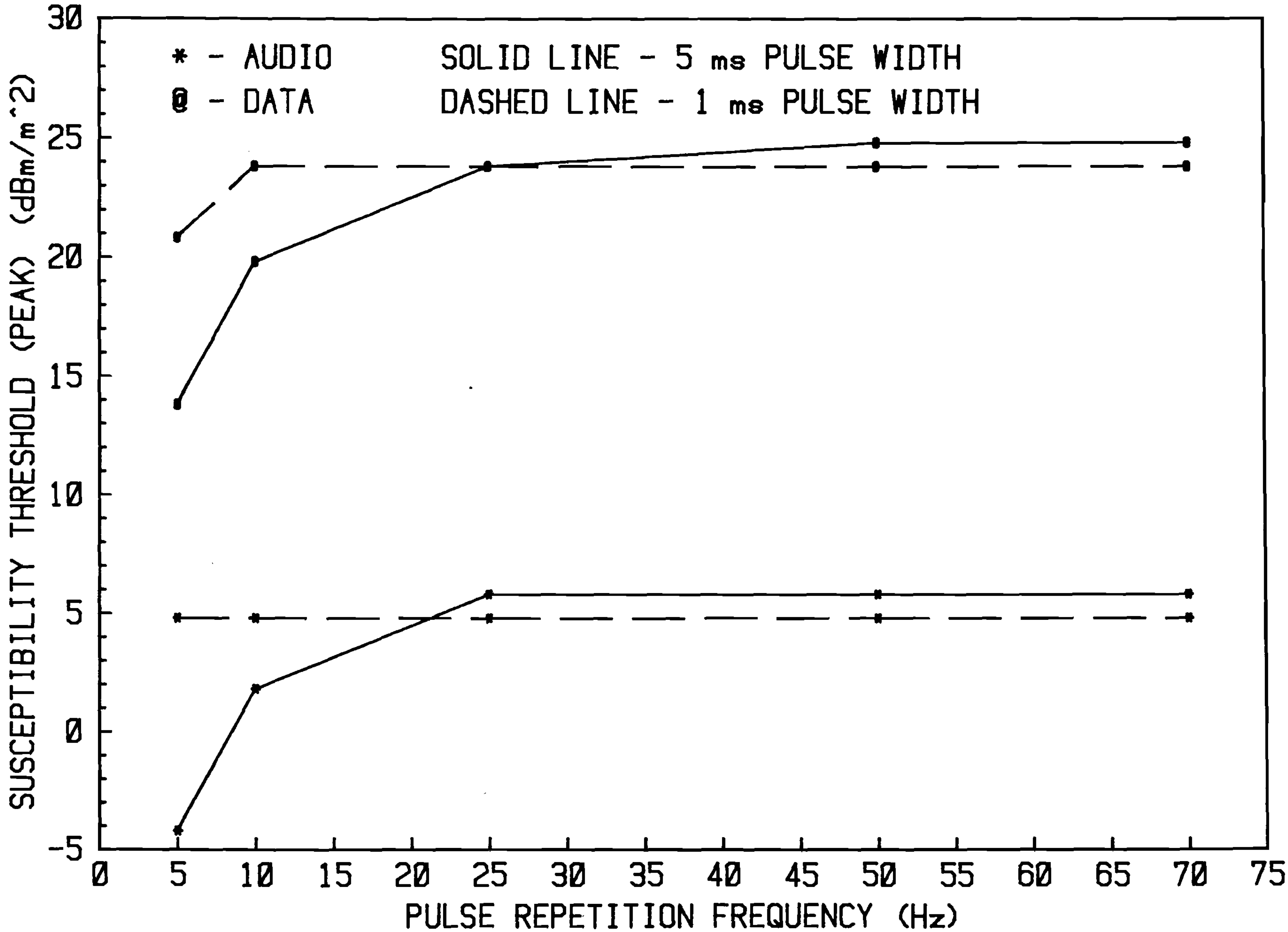


Figure 38. Radiated Susceptibility Thresholds versus Pulse Repetition Frequency for Receiver/Multiplexer -- Channel 1-5-12 (60 - 64 kHz).

individual receiver test channels, since the objective was to identify a single threshold level which represented the lowest susceptibility threshold level for the microwave receiver and receiver/multiplexer combination.

Receiver Alone Test Data Adjustments

A review of Figure 34 reveals that for the receiver alone tests, the "average" audio threshold level for a 5 ms pulse width is roughly 24 dBm/m^2. For a 15 ms pulse width, the threshold level drops to approximately 19 dBm/m^2. Thus to achieve a worst-case threshold level in terms of pulse width, the threshold levels of the susceptibility data presented in Section 2.7.2.1 should be lowered by 5 dB.

The effects of PRF on threshold levels recorded in the receiver alone test configuration are given in the data of Appendix A. Note from these data that the lowest threshold levels generally occur at the standard PRF of 70 pps. Hence, for the receiver alone configuation, no adjustment is required to reflect PRF effects.

From Figures 31 and 32 and Table VI, it can be seen that the lowest threshold level measured in the receiver alone test configuration was +20 dBm/m^2 (from Figure 32 at 420.8 MHz). When this level is lowered by 5 dB to reflect PW effects, the adjusted, worst-case audio susceptibility threshold for the receiver alone test configuration becomes +15 dBm/m^2.

Receiver/Multiplexer Test Data Adjustments

For the receiver/multiplexer test configuration, the interference signal pulse width had no significant effect on interference thresholds. Thus, no adjustments to susceptibility thresholds are required for this parameter.

The data of Appendix C show the effects of PRF on the susceptibility thresholds recorded in the receiver/multiplexer test configuration. A review of Figures C-1 through C-5 shows that on the average, both the audio and data thresholds decreased by approximately 10 dB as the PRF was changed from 70 pps to 5 pps (the 5 ms PW data was used to reflect worst-case changes). Hence, the threshold levels recorded in this test configuration should be lowered by 10 dB to reflect the effects of this parameter change.

A review of the data in Appendix B reveals that the lowest audio and data thresholds recorded were 6 dBm/m^2 and 18 dBm/m^2, respectively. When those levels are reduced by 10 dB to reflect PRF effects, the adjusted, worst-case audio and data susceptibility thresholds for the receiver/multiplexer test configuration become -4 dBm/m^2 and 8 dBm/m^2, respectively.

3. ELECTROMAGNETIC ENVIRONMENT CREATED BY PAVE PAWS

3.1 General

This section describes the procedure followed in predicting the electromagnetic environment which will be created by the PAVE PAWS radar. This procedure basically involved (1) the identification of the nominal operating characteristics of the PAVE PAWS system, and (2) the use of these identified system characteristics and the terrain characteristics in the vicinity of the planned radar site to predict radar-generated field strength levels. The predicted field strength levels were used in conjunction with the measured susceptibility data of Section 2 to access the potential for interference to the UHF and microwave communications receivers.

3.2 PAVE PAWS System Description

3.2.1 Site Description

The PAVE PAWS radar will be located at the southern end of Robins Air Force Base (RAFB) at coordinates 32° 34' 48" N latitude and 83° 34' 07" W longitude and at a terrain elevation of 82 meters (270 feet). Robins Air Force Base is a Strategic Air Command (SAC) base and an Air Logistics Command (ALC) facility. The main portion of RAFB is northwest of the PAVE PAWS site and is situated in the backlobe of the antenna. The town of Warner Robins is located just beyond RAFB and is also in the backlobe of the antenna. Terrain to the north, east, and south of the site is swampy with dense woods and is essentially flat.

3.2.2 General System Characteristics

PAVE PAWS is a self-contained, fixed-base, solid-state, phased-array radar system. Each site contains a dual-faced, phased-array radar, data processing and control hardware and software, communications, and environmental control facilities. A five story facility houses the PAVE PAWS hardware. The two array faces make up two walls of the triangular building, and each face of the antenna is composed of 5354 active elements in a 31-meter diameter circular array.

The PAVE PAWS azimuth scan will encompass 240° by originating at a bearing of 10° true (T) and proceeding clockwise to 250°T. The backlobe of the antenna extends from 280°T to 340°T. Elevation coverage is from 3° to 85°.

The system to be installed at RAFB will have a 9.5 dB increase in effective radiated power relative to that of previous PAVE PAWS radars. One half of this increase in effective radiated power is due to an increase in antenna gain, because of conversion of all dummy elements to active elements. The other half of the increase results from the enhancement of transmitter power to all the new active elements. The RAFB PAVE PAWS system parameters are listed in Table VIII.

Each element of the antenna is driven by a separate solid-state module exhibiting a low-pass filter and four-bit phase shifters. The antenna main-beam can be formed in any desired forward direction by properly controlling the phase shift for each element on each transmit or receive pulse. The beam displays a width of 1.37° and can be steered $\pm 60^{\circ}$ from the boresight direction in azimuth and from 3° to 85° in elevation. A radar search fence may be generated by electronically steering pencil shaped beams over a surveillance volume of 240° in azimuth and one beamwidth in elevation originating at the minimum 3° elevation level.

TABLE VIII

RAFB PAVE PAWS PARAMETERS[a]

Frequency	24 crystal-controlled selectable frequencies within the 420-450 MHz band
Peak Power[b]	92 dBm
Pulse Widths	0.005 ms - 16 ms
Pulse Rise and Fall Times	100 ns
Spurious Emission Level	-90 dB, referenced to the fundamental power
Harmonic Level	-90 dB, referenced to the fundamental power
Noise Figure	2.9 dB
IF 3-dB BW	8 MHz
Antenna	2 planar phased-array faces oriented to provide 240 coverage, corporate feed, 112 subarrays/ face, approximately 48 elements/subarrays.
Antenna Gain per Face[c] (Including Losses)	Mainbeam 43 dBi (midband) First Sidelobe 25 dBi Second Sidelobe 19 dBi Backlobe -7 dBi
Ant. Polarization	Right circular, transmit Left circular, receiver
Beam Width	1.37°

[a]Data derived from Reference 1.

[b]Increased power level value supplied by the System Program Office for the RAFB site, only.

[c]Antenna sidelobe levels calculated for circular aperture with uniform illumination.

3.2.3 Antenna Characteristics

The characteristics of the RAFB PAVE PAWS antenna are considered in this section, with emphasis being placed on those features that are of importance in determining the radiation levels in the surrounding regions.

3.2.3.1 Antenna Size

The single most important feature of the antenna affecting radiation levels is simply its size. The directivity of an antenna determines how effective it is in concentrating its radiated power into a small angular region. Directivity is given by the expression

$$D = (4\,\pi/\lambda^2)\,A^{\eta} \tag{3}$$

where λ is the wavelength of the radiated signal, A is the area of the antenna aperture (an imaginary surface immediately in front of the antenna through wich all of its radiated power must pass), and η is the aperture illumination efficiency. Aperture illumination efficiency is a measure of how uniformly the radiated power is distributed over the antenna aperture. When the RAFB PAVE PAWS is transmitting, all of its array elements are excited equally; therefore, its aperture is said to be uniformly illuminated, and its illumination efficiency is 100% ($\eta = 1$). At a frequency of 450 MHz, the wavelength, λ, is 0.67 meters. The PAVE PAWS antenna has a circular aperture that is 31 meters in diameter, giving it an area of approximately 755 square meters; therefore, from the above equation, its directivity at 450 MHz is 21,341 or 43.3 dB expressed as 10 $\log_{10}$ of the gain ratio. This means that the power strength (watts per square meter) at the peak of the main beam of the PAVE PAWS antenna is 21,341 times as high as it would have been had the power been radiated uniformly in all directions. Because the aperture is uniformly illuminated, this field strength is the highest that it is practical to achieve at this frequency from an aperture of this size.

Actually, the main beam field strength is not of primary concern under this program. Rather, it is the fact that higher main beam power will result in higher power being distributed throughout the sidelobes of the antenna pattern. It is the "near-in" sidelobes of the PAVE PAWS antenna pattern that will be illuminating the Georgia Power Company communication system.

3.2.3.2 Aperture Illumination and Pattern Shape

The field intensity (voltage) pattern of a uniformly illuminated circular aperture is given by the function

$$E(\theta) = \left[1 - T_x^2 - T_y^2 \right]^{\frac{1}{2}} J_1(\theta)/\theta \tag{4}$$

where J_1 represents the first order Bessel function of the first kind and

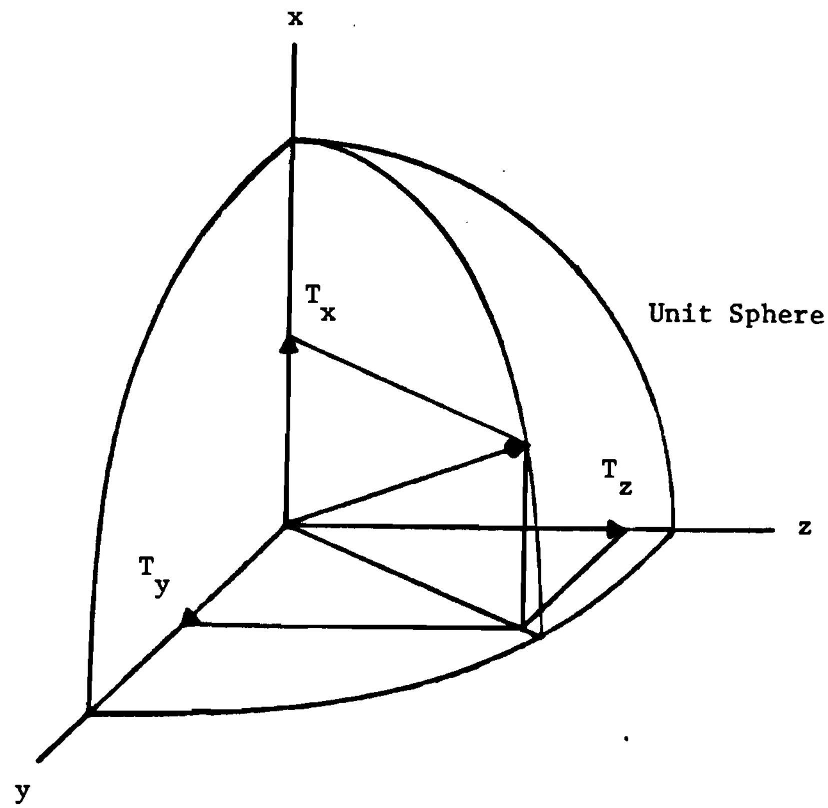
$$\theta = 2\pi(R/\lambda) \left[T_x^2 + T_y^2 \right]^{\frac{1}{2}} \tag{5}$$

T_x and T_y are the cosines (direction cosines) of the angles from the direction for which the pattern value is being evaluated to the x and y axes, respectively, of the antenna coordinate system (Figure 39). The radical in Equation 4, then, is the sine of the angle to the broadside (z) axis. R is the aperture radius. The shape of this pattern out to the fourth sidelobe is shown in Figure 40, where the magnitude is given in dB relative to the peak of the main beam. Sidelobe levels are given in Table IX for a frequency of 450 MHz.

TABLE IX

SIDELOBE LEVELS FOR IDEAL PATTERN

Sidelobe	Level (dB)
1	-17.6
2	-23.8
3	-28.0
4	-31.1



NOTE: Antenna Aperture (face)
is in x-y plane

Figure 39. Antenna Coordinate System.

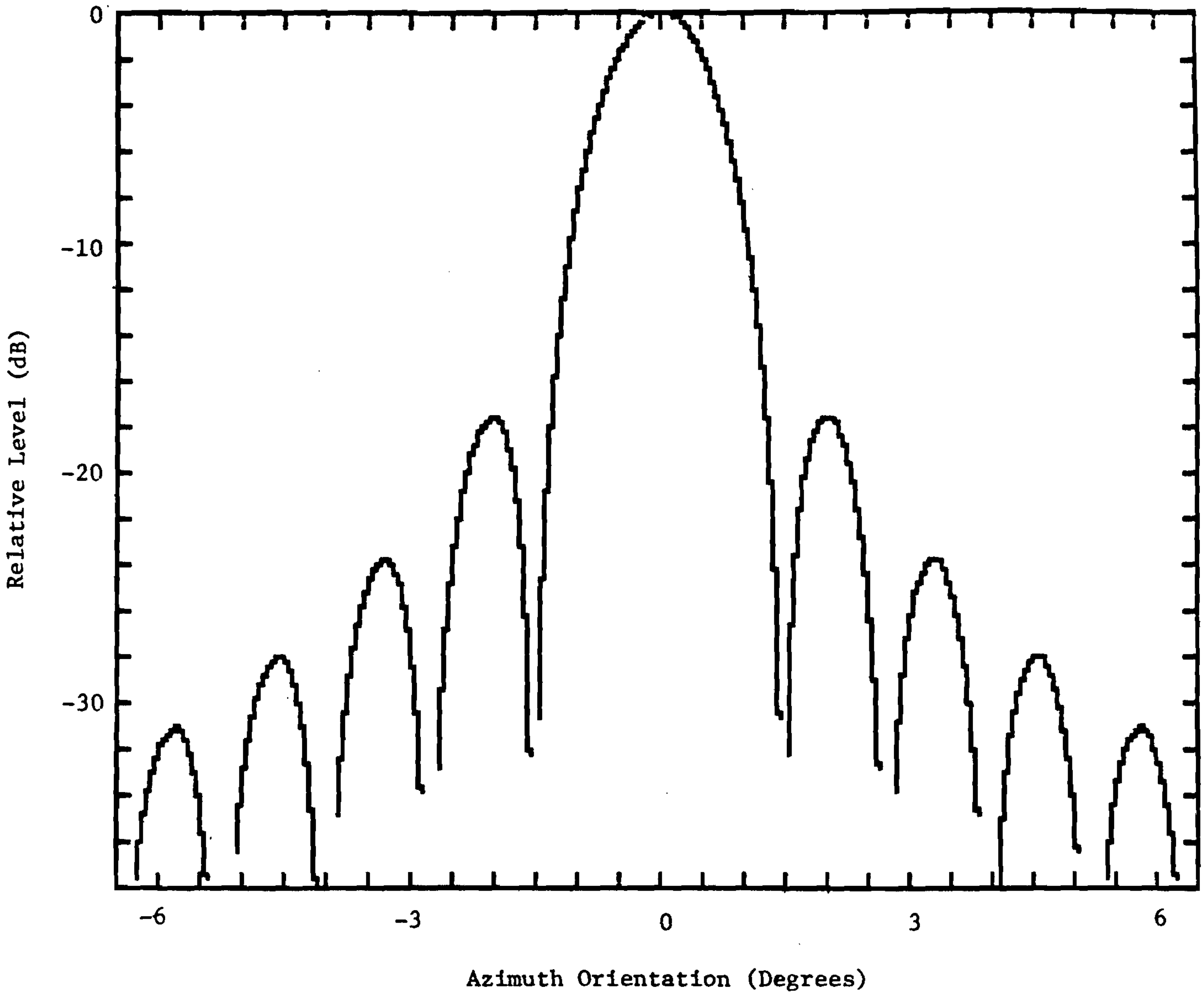


Figure 40. Ideal Broadside Pattern.

Equation 4 is actually the ideal pattern for a continuous aperture, but it is very accurate for an aperture of discrete elements for the main beam and a much larger region around the main beam than is shown in Figure 40. It can safely be assumed to represent accurately the ideal unscanned (pointed broadside to the aperture) RAFB PAVE PAWS antenna pattern. By ideal, it is meant the pattern when no amplitude and phase errors are present in the aperture illumination function. For a real array, of course, some errors will always be present. The effects of these errors will be discussed shortly.

In Equation 4, the leading radical is known as the element pattern, because it is the pattern that would be obtained (ideally) if only one of the elements were radiating in the presence of the others. The rest of the function is called the array factor. It is the pattern that would be obtained if all of the elements could radiate isotropically.

3.2.3.3 Pattern Shape Variation With Scan

Unlike the patterns of mechanically scanned antennas, the pattern of a phased array antenna does not remain fixed in shape as it is scanned. Instead, it broadens more and more as it is scanned away from its broadside axis. To incorporate this broadening aspect of the antenna pattern into Equation 4 it is necessary to modify Equation 5 as follows:

$$\theta = 2\pi(R/\lambda)\left[(T_x - T_{xo})^2 + (T_y - T_{yo})^2\right]^{\frac{1}{2}} \tag{6}$$

Figure 41 shows the ideal PAVE PAWS antenna pattern when it is scanned to 60° in azimuth.

3.2.3.4 Pattern Model for Radiation Level Calculations

The patterns shown in Figure 40 and 41 are ideal patterns. In an actual antenna system, there are always some amplitude and phase errors in the aperture illumination function. These have several causes. Usually, one of the most important sources of phase errors is the quantization effect of the

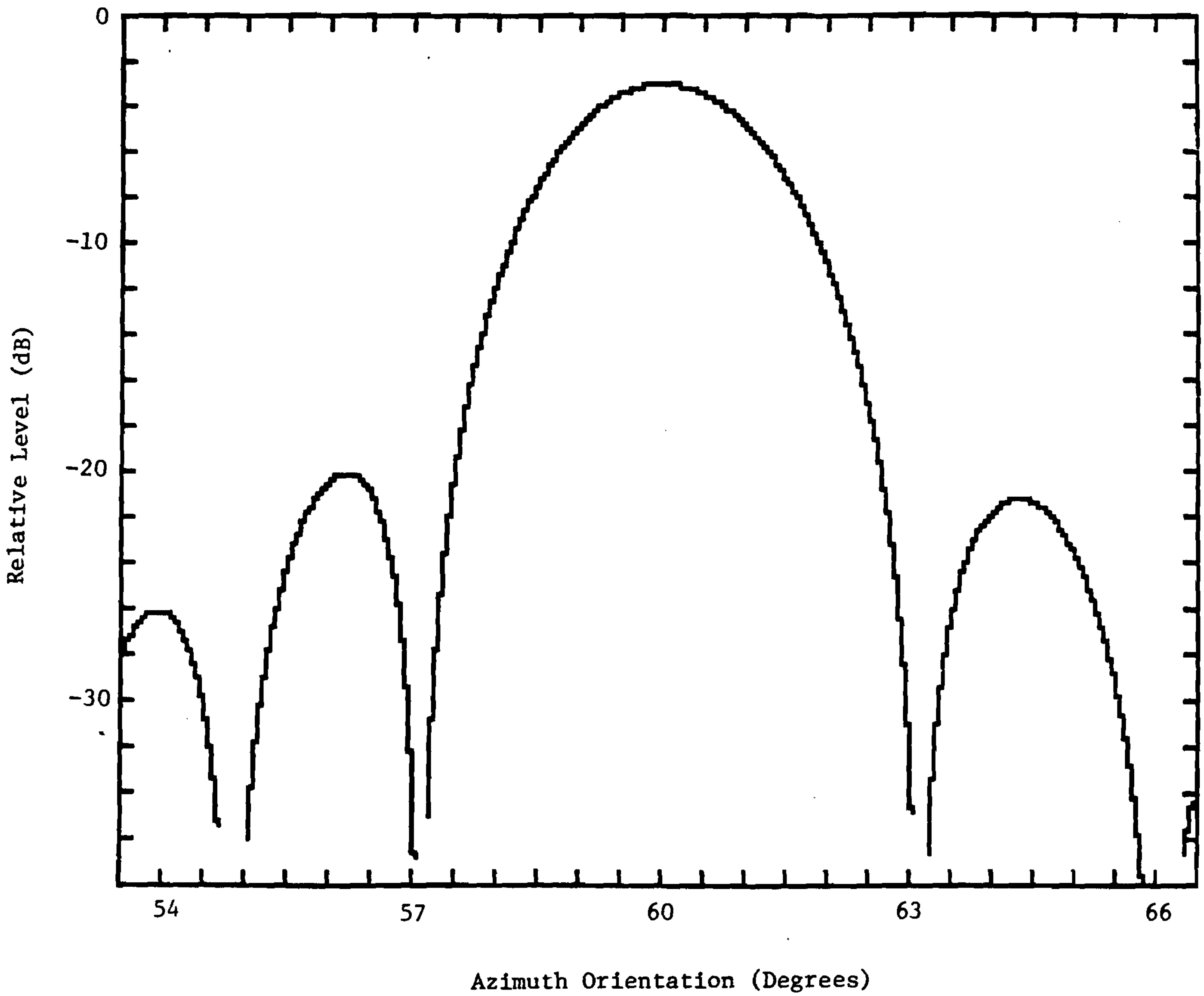


Figure 41. Beam Broadening with Scan.

digital phase shifters. These phase shifters can only change phase in 22.5 degree steps in the case of the PAVE PAWS array. Usually, the quantization errors are deliberately randomized so that their effects are quite uniform for all scan angles. Other sources of errors are associated with the manufacturing or fabrication tolerances of the various components of the array system. These tolerances may be electrical or mechanical (positional). The effect of these errors, as far as the radiation level is concerned, is an increase in sidelobe levels. Measured data for presently existing PAVE PAWS radar systems indicate that the first four sidelobe levels may be higher than the theoretical values given in Table IX. The actual levels for the RAFB PAVE PAWS are difficult to assess at the present time since the radar has not yet been built. Beyond the fourth sidelobe, the real antenna pattern deviates sharply from the ideal pattern because the fifth and higher sidelobes become essentially random in structure. These higher order sidelobes have peaks no less than 30 dB below the main mean peak power level [3]. This randomness is because, at this level, the sidelobes are being determined by the random system errors, rather than by the characteristics of the theoretical pattern funtion.

Because the actual pattern may differ from the ideal pattern, the location of the nulls in the ideal pattern may not reflect the actual field strength at those pattern positions, since the mathematically precise null locations of the ideal pattern may be "smeared out" or "filled in" by the actual radar's pattern. Therefore, in modelling the antenna pattern, nulls are filled in. The importance of filling in the nulls can be seen in the case where the radar is operating at its mimimum elevation angle of three degrees, since from the ideal pattern the power radiated in the horizontal direction would lie near a null between the first and second sidelobes. Since the location of this null cannot be well defined for the actual radar pattern, a worst-case philosophy is maintained by assuming that the radiated field strength at this position corresponds to the peak of the third sidelobe. Figure 42 illustrates the antenna model actually used. For each sidelobe, the sidelobe level is maintained out to the angular direction at which the theoretical sidelobe peak occurs. The pattern then descends along the theoretical curve to the level of the next sidelobe peak.

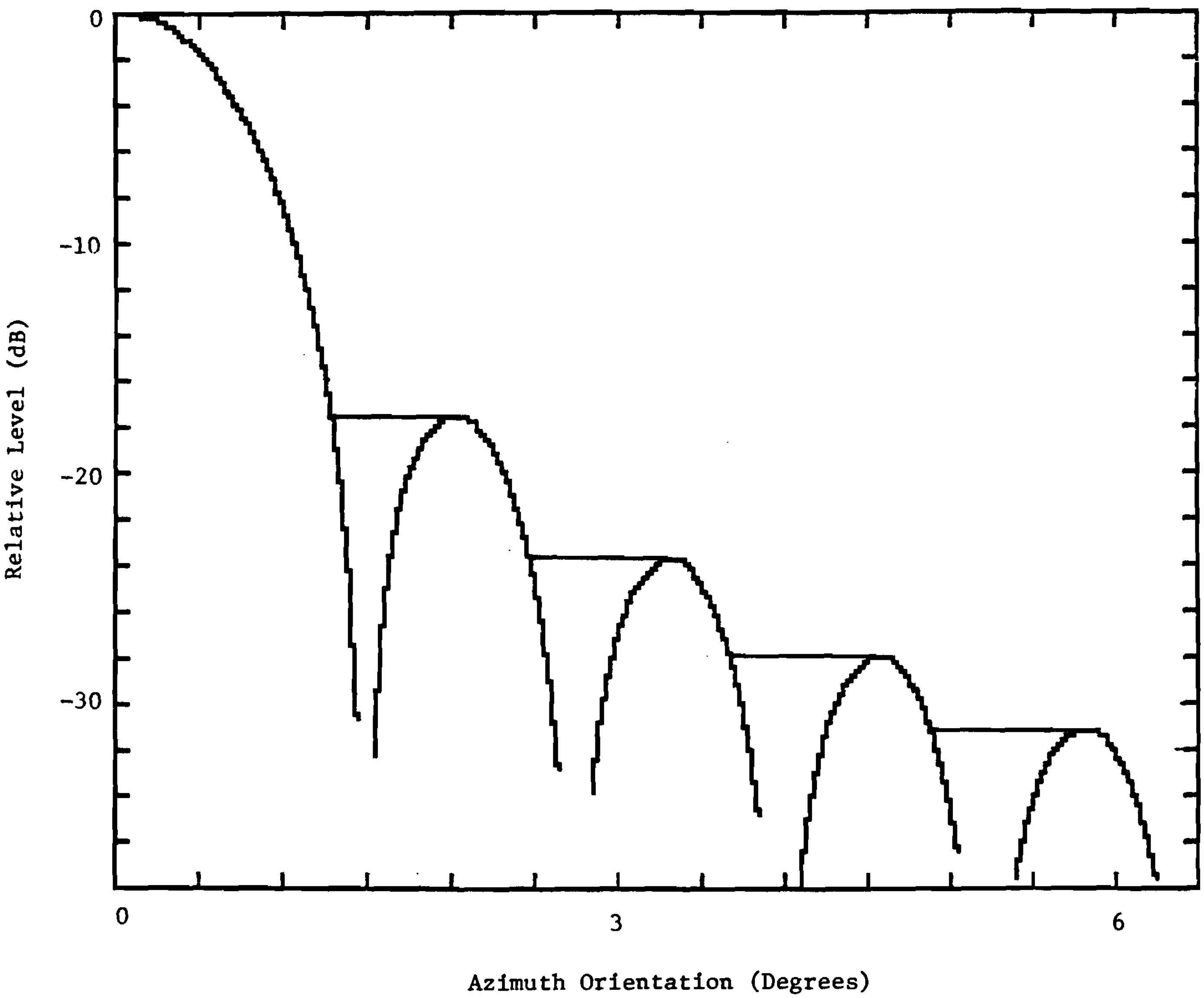


Figure 42. Antenna Pattern for Radiation Level Calculations.

3.2.3.5 Frequency of Illumination in a Given Direction

When the RAFB PAVE PAWS system is performing long or short range surveillance, the beam is usually maintained at its minimum allowable elevation angle of three degrees. This is the beam elevation at which ground or tower positions will be subjected to maximum radiation levels. Depending on terrain or tower heights, these positions may be illuminated by the first or second sidelobe. How often will this occur? To obtain an approximate answer to this question, it will be assumed that the beam is being continually maintained at its minimum elevation scan angle. This is only a slightly pessimistic approximation. In scheduling tasks for the PAVE PAWS system, time is divided into 65 ms (millisecond) intervals called "resources." From resource to resource, the beam will be switched rapidly between widely spaced azimuth directions in a complicated sequence that is repeated every 45 seconds. For present purposes, the sequence may be considered random, except for positions near the extreme scan angles. These positions will be illuminated somewhat more frequently than those near zero degrees azimuth to compensate for the slight reduction in gain with increasing scan angle. The beam may also be moved during a resource, which is one justification for "blurring" the sidelobes as shown in Figure 42.

During a 45 second sequence, about 692 sixty-five millisecond resources will be completed, each one representing a beam position (ignoring the possible small beam position changes during the resource period). Considering the discussion in Section 3.2.3.3, it will be assumed that beam positions are spread more or less equally in terms of the sine of the azimuth scan angle, because, in this way, the required scan volume is covered most efficiently. It can then be shown that, if the number of beam positions in a given azimuth angle segment is selected to compensate for the gain reduction with scan, the beam positions in a segment (during a 45 second sequence) will be given by the function

$$\Delta h = k \;\; \Delta(\sin \phi_a)/\cos \phi_a \qquad (7)$$

where k has the value $3(692)/2\pi$ or 330.4 and ϕ_a is the azimuth scan angle. Since individual pulses in a resource will probably not be distinguishable, Equation 7 can be assumed to give the number of "hits" per 45 second sequence in the azimuth segment. The factor $\Delta(\sin \phi_a)$ is selected to encompass the portion of the beam assumed to be significant.

To include the first and second sidelobe, $\Delta(\sin \phi_a)$ should be about 2 sin 4^o (see Figure 40). At $\phi_a = 60^o$, Δh is 92 hits in 45 seconds, or about 2 per second. At $\phi_a = 0^o$, it will be one per second.

These approximations thus indicate that the "rate" at which a given equipment will be exposed to the PAVE PAWS signal will be on the order of 1 to 2 times per second.

3.2.4 Spectrum Characteristics

3.2.4.1 General

Emissions from existing PAVE PAWS are comprised of 54 ms radar resources as indicated in Figure 43 (RAFB PAVE PAWS resources are expected to last 65 ms). The types of resources employed may be either search (S), track (T), or calibration (C). Four types of track modes (T_1, T_2, T_3 and T_4) are possible and are depicted in Figure 44. Long-range search templates are similar to T_1 track templates, while short-range search templates are similar to T_3 templates. During the transmit interval of a resource, the number of pulses transmitted can vary from one to eight (except for T_4, where only one pulse is allowed), depending on the characteristics of the targets or the type of search involved.

Each transmitted pulse is at a different frequency. Twenty-four different frequencies between 420 and 450 MHz are used and are depicted in Table X. The lowest center frequency is 421.3 MHz and the highest center frequency is 448.7 MHz (with a 1 MHz chirp width, the lower and upper frequency limits of concern will be 420.8 MHz and 449.2 MHz, respectively.). The 24 frequencies are divided into three groups, each containing eight frequencies. One group of eight frequencies is used for the first 31 resources, the second group for the next 31 resources, and third group for the next 31 resources. The 31 resource grouping allows for discrimination against

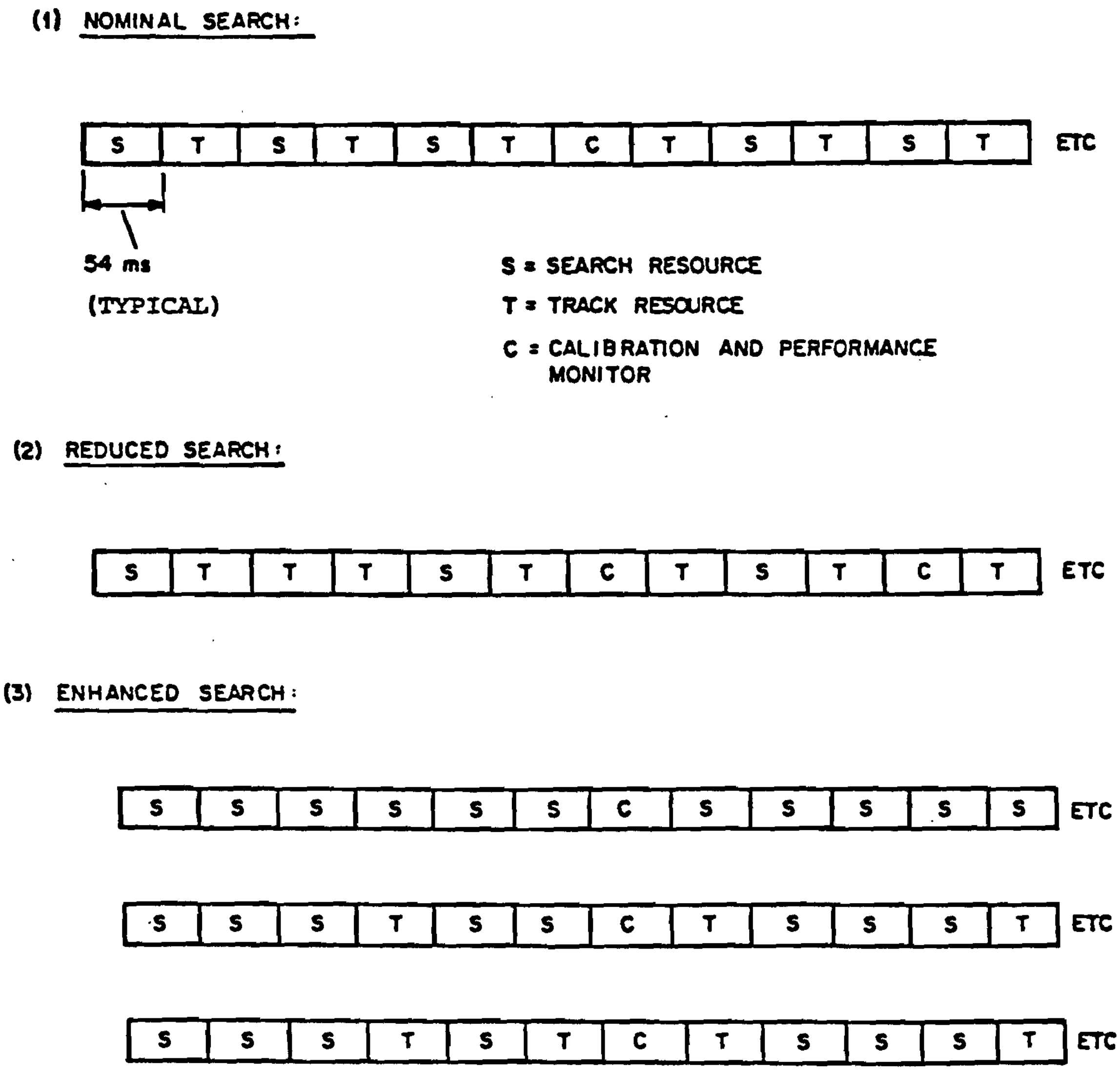


Figure 43. PAVE PAWS Basic Search Modes.

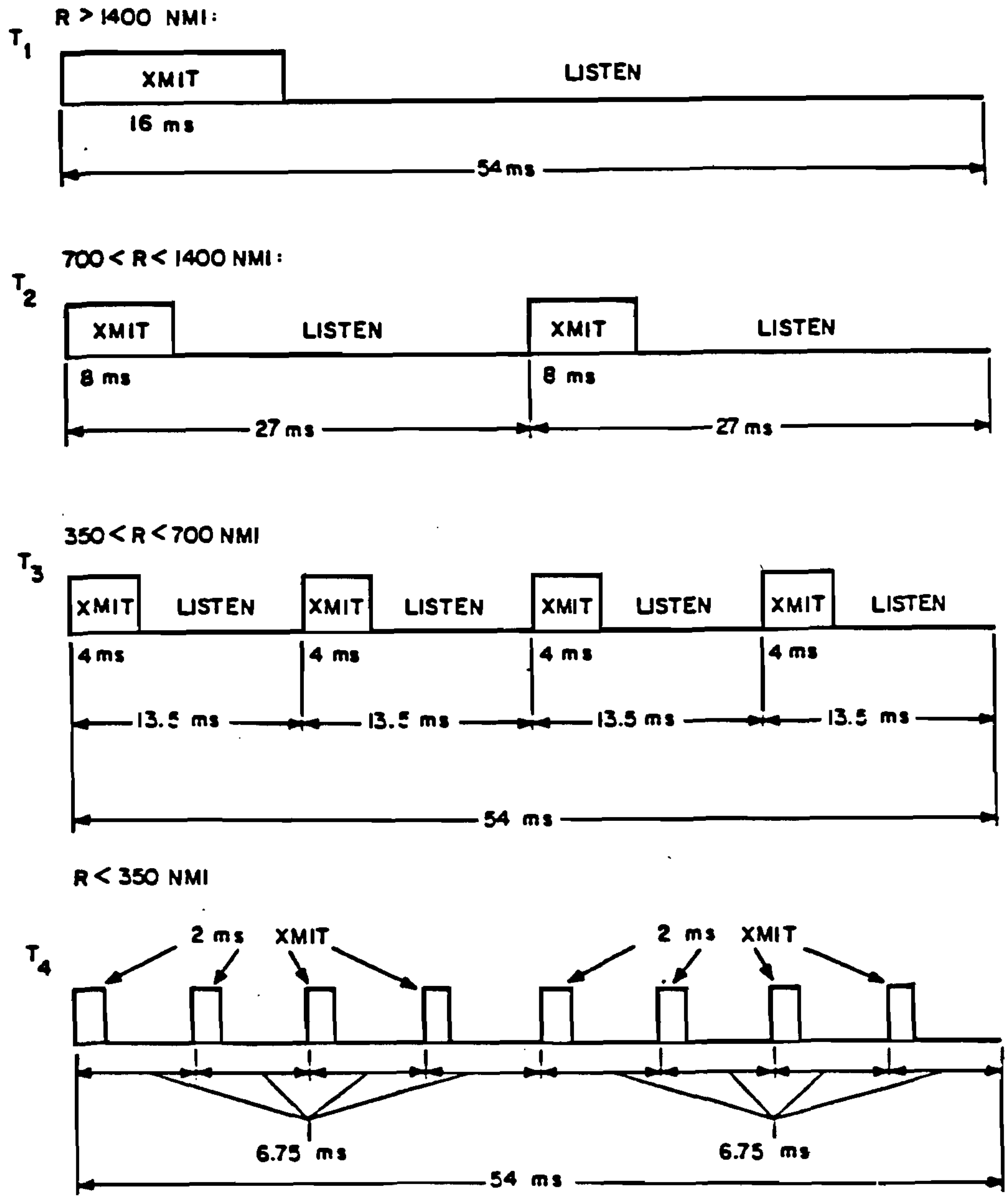


Figure 44. PAVE PAWS Track Templates.

TABLE X

PAVE PAWS FREQUENCIES

Channel Number	Center Frequency (MHz)			Frequency Set		
1	421.3			A		
2		422.5			B	
3			423.7			C
4	424.9			A		
5		426.1			B	
6			427.3			C
7	428.5			A		
8		429.6			B	
9			430.8			C
10	432.0			A		
11		433.2			B	
12			434.4			C
13	435.6			A		
14		436.8			B	
15			438.0			C
16	439.2			A		
17		440.4			B	
18			441.5			C
19	442.7			A		
20		443.9			B	
21			445.1			C
22	446.3			A		
23		447.5			B	
24			448.7			C

target returns from the moon. Each transmitted pulse uses the next higher frequency until the group of eight has been used. Then, that same group will be reused as often as necessary for the 31-resource interval. The repetition time of any given frequency is a function of the number of pulses employed in each resource. The number of pulses utilized in each resource is dependent on the characteristics and positions of targets in track as well as system tasking.

The emission spectrum for PAVE PAWS is different for each type of pulse that is transmitted. Seven pulse types are possible for track modes. Pulse widths for the track mode are 16, 8, 4, 1, 0.5, or 0.25 ms. The chirp width for these track pulses is 1 MHz. Pulses in a search resource exhibit pulse widths of either 8, 5, or 0.3 ms, and display a chirp width of 0.1 MHz. Approximately every eighteenth resource is a calibrate resource. The calibrate pulse employs a pulse width of 0.005 ms. Emission spectra for these different types of pulses have been calculated by Siemen [1].

Because the simulated PAVE PAWS signal used in the receiver susceptibility measurements was generated by laboratory instrumentation, the question arises as to possible differences in the spectrum of this signal and the actual PAVE PAWS emission spectra which will exist when the radar becomes operational. In particular, will differences exist which are of sufficient magnitude to cause significant "errors" in measured receiver susceptibility thresholds and in the identification of potential interference problems?

The actual emission spectra of the PAVE PAWS radar at Robins AFB will not be precisely known until the radar is installed and measurements are taken. Furthermore, no measured data were found which identified the emission spectra of the PAVE PAWS system which are already in operation. Hence, in order to compare the spectral characteristics of the simulated test signal with those of the PAVE PAWS signal, it was necessary to model the PAVE PAWS spectra using analytical techniques. Such techniques will provide realistic approximations of actual pulsed signal spectra provided that: (1) the signal parameters (pulse width, rise time, etc.) are accurately defined; and (2) the system hardware will accurately reproduce the desired signal wave form (i.e., without distortion, noise, etc.).

Comparisons between the anticipated PAVE PAWS spectrum and the simulated test signal spectrum are illustrated in Figure 45 for specific signal parameters. The solid line in the figure (a repeat of Figure 3) shows the envelope of the measured spectrum of the simulated signal used in the test specimen receiver susceptibility measurements. The dots in the figure are calculated values for the envelope of the spectrum for a chirped, pulsed signal with a pulse width of 5 ms, a chirp width of 1 MHz, and a rise time of 100 ns (stated rise time of PAVE PAWS pulses is 100 ns as given in Table VIII). The calculations were performed using both a Georgia Tech computer program for calculating pulsed spectra characteristics and a method which was developed for bounding the spectra of chirped signals [4]. Both methods presented identical results.

A review of Figure 45 reveals that except for the frequency region around 6 MHz, the "100 ns PAVE PAWS spectrum" (circles) is essentially identical to the spectrum of the simulated signal (solid line) used for susceptibility tests. The variation near 6 MHz is not unexpected since two different rise times are involved (The simulated signal rise and fall times were approximately 50 ns as noted in Section 2.4.2.).

Also calculated and shown by the dotted line on Figure 45 is the theoretical envelope of the spectrum of a chirped, 5 ms pulse with zero rise time. The zero rise time spectrum envelope represents an upper bound for the spectral characteristics of a pulsed signal. Note that in the frequency range of primary concern for the UHF receivers (i.e., 1 - 8 MHz), the envelope of the simulated signal is near this theoretical upper bound. Thus, the susceptibility thresholds recorded on the UHF receivers should be close to worst-case interference conditions.

From the above data, it is concluded that the simulated test signal spectrum will be reasonably close to that of the PAVE PAWS signal, and that the susceptibility data recorded provides a valid basis for performing interference assessments. Differences between the simulated and actual spectra are most likely to exist at frequencies greater than 8 - 10 MHz from the center of the spectrum. At these frequencies, the spectral character-

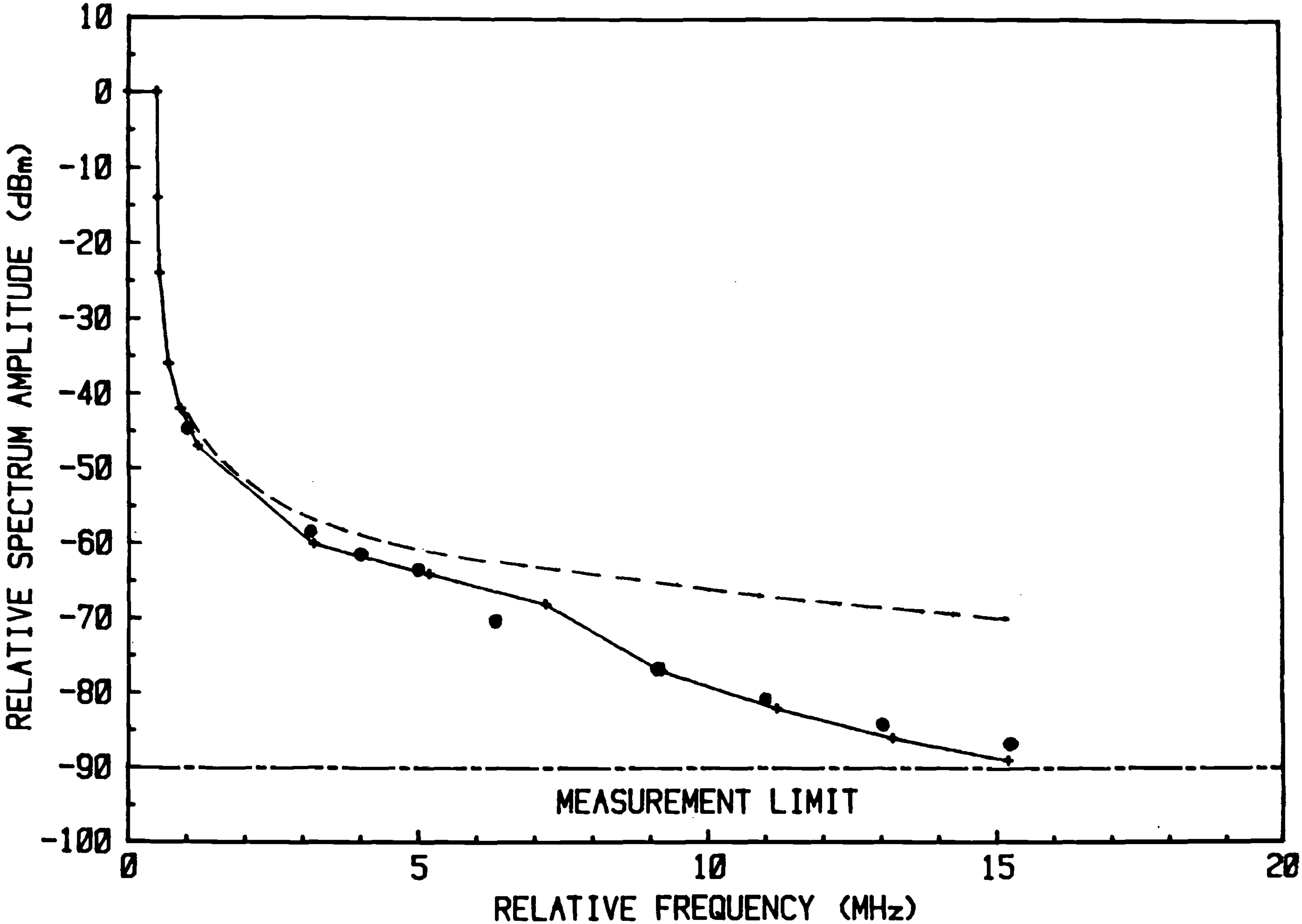


Figure 45. Interference Signal Spectrum Comparisons.

istics will be highly dependent upon the specific characteristics of the pulse waveform (particularly rise time) and the accuracy with which the waveform is reproduced by the system hardware.

It is to be noted that within the PW, PRF and chirp width ranges specified for PAVE PAWS, the primary effects of changes in these parameters on the spectrum envelope will be at frequencies near the center frequency of the pulse. At frequencies greater than 1 - 2 MHz from the center frequency, the spectrum envelop will remain essentially constant with changes in these parameters. Thus, it is not surprising that changes in PW, PRF, and chirp width had little effect on the measured susceptibility thresholds of the UHF receivers. Note from figures 14, 15, and 16 that these thresholds remained relatively constant with changes in the parameters.

3.2.4.2 Frequency Scanning Considerations

PAVE PAWS emissions which are most likely to cause interference to the UHF receivers will occur when track pulses are centered at the highest transmission frequency (448.7 MHz) or at receiver spurious response frequencies. Since the PAVE PAWS pulse scheduling and track distribution model are classified, the frequency of occurrence of these worst-case frequencies is unknown. However, some rough approximations of frequency scanning can be made which are helpful to understanding interference effects in the UHF receivers. For example, assuming that the highest pulse repetition frequency (track template T-4 in Figure 44) occurred in every resource of a 31-resource interval, and assuming that one frequency group is reused for each resource in this interval, then a given frequency in this group would occur once each resource period, or approximately 18.5 times per second. Also, assuming that the set of frequencies which contained the given frequency will be employed only within every third resource interval, then a time period equivalent to two resource intervals (3.35 seconds) would elapse before the given frequency is again repeated at the 18.5 times per second rate. Based on this example, it is evident that the "average" rate at which a receiver will be exposed to a given worst-case frequency will be considerably less than the 70 pps rate used in the interference susceptibility measurements.

3.3 PAVE PAWS Field Strength Predictions

3.3.1 General

The PAVE PAWS radar, when operating at its maximum elevation angle of three degrees, will radiate a significant amount of energy in the horizontal direction. This energy is due to the first and second sidelobes which lie slightly above and below the horizontal, respectively. Because of the variation in terrain height radially away from the radar site, the power radiated in the direction of a receiver can vary considerably. That is, one may see the full power of the first sidelobe or, in some cases, part of the main beam may be encountered. An accurate prediction of the field strength levels in the area surrounding the RAFB site was a critical part of this effort. Once field strength estimates had been made for an area, they were compared to the measured susceptibility thresholds of the test specimen receivers to identify potential interference problems.

If the radar were operated at higher elevation angles, then higher order sidelobes, and hence less power, would radiate in the horizontal direction. Thus, the minimum elevation level of three degrees was a worst-case situation. For the field-level prediction studies that follow, a main-beam elevation of three degrees was assumed throughout. Also, to conform to the worst-case interference philosophy, it was assumed that both the main-beam and the receiver site had the same azimuth.

3.3.2 Topographic Considerations

In order to estimate the field strength levels in the area surrounding the SEPP site, the effects of the terrain on the energy propagation had to be considered. The radar's power characteristics and radiation pattern were known, and the main beam field strength, FS, in free-space is given by the well-known formula

$$FS = \frac{P_t \; G_t}{4 \pi R^2} \quad (W/m^2) \tag{8}$$

where P_t is the power transmitted in watts (1.75×10^6 watts), G_t is the gain of the transmitter (20,500 at 435 MHz), and R is the distance away from the transmitter in meters. The effect of the terrain on the field strength was incorporated by first writing Equation 8 in the form

$$FS = P_t + G_t - 20 \log R - 10 \log (4\pi) \tag{9}$$

where FS is the field strength expressed in dBm/m^2 and P_t and G_t are expressed in dB. Then the effect of the terrain was incorporated into (9) as a factor, L, expressed in dB (usually a loss). Thus,

$$FS = P_t + G_t - 20 \log R - 10 \log (4\pi) - L \tag{10}$$

Next , the terrain loss factor, L, had to be determined. The effect of the terrain on the propagation of electromagnetic fields depends on a number of factors: for instance, the terrain contour profile, the surface refractivity, constitutive parameters (dielectric constant and conductivity of the soil), and the type of climate. A Georgia Tech propagation model, the Longely-Rice model [5], was used to predict transmission loss over terrain. This model is implemented in FORTRAN on a Digital PDP-11 computer.

The Longley-Rice model consists of two parts: an area prediction model, and a point-to-point prediction model. The area model was used to predict transmission loss over a large geographical area on a statistical basis. The point-to-point model was used to predict the transmission loss over terrain connecting two explicit points -- one being the transmitter site and the other the receiver site. The point-to-point model yielded results that were also statistically based in the sense that the associated constitutive parameters and terrain type (wooded, rocky, grassy, etc.) were only known statistically. However, the terrain profile in the point-to-point model was explicit. In the area model, the terrain contours were only known on a statistical basis and therefore the point-to-point model was the more accurate method.

In either case, the contour profile of the geographical area under study had to be obtained. These data were used directly in the point-to-point model. For the area model, the profile data were pre-processed so that a statistical profile of the terrain could be obtained. So, to use the Longley-

Rice model, a geographical contour data base had to be established. This data base was accomplished by obtaining sectional maps for a 25 mile radius of the area around the SEPP site from the U.S. Geological Survey. These maps contained the terrain elevation contours. Radials were drawn at 15^{o} intervals centered at the RAFB site and extended to 25 mile lengths. Along each radial the elevation was read at 1 mile intervals. This process gave 600 elevation data points over approximately a 2,000 square mile area. These data were then pre-processed by the Longley-Rice model computer program to yield a statistical discription of the terrain. Because of the geographical similarity of the region outside a 25 mile radius from the radar site, it was assumed that the computed statistical terrain profile would be valid for extended distances away from the radar site. It was expected that field intensity levels for distances up to 100 miles would be necessary to obtain.

The overall terrain surrounding the site was divided into six sectors of 60 degrees each. These sectors were chosen so as to divide the total area into regions of similar topography. The statistical pre-processing of the Longley-Rice model was done for each sector instead of for the entire area. By dividing the total area into six sectors, it was felt that a better statistical picture of a given sub-area could be attained, since it was noted that in some directions leading away from the radar site the terrain was relatively flat, while in others it was quite hilly. Thus, the area model could be used in each of the six sectors, each relying on its own terrain statistics, instead of relying on the overall statistics of the entire region. The division of the area into sectors, relative to the scan limits of the radar, is shown in Figure 46.

Other input data into the Longley-Rice model were: the transmitter frequency (435 MHz, the median radar frequency), the receiver and transmitter heights, given as height above local ground (16.31 m for the radar transmitter and 1.5 m for ground level or 105.16 m for top-of-tower level at the receiver), the surface refractivity (320 for central Georgia), type of environment (continental temperate), the mean terrain surface level, the dielectric constant (9 was chosen as a typical value), and the soil conductivity (0.04 mhos/m for central Georgia).

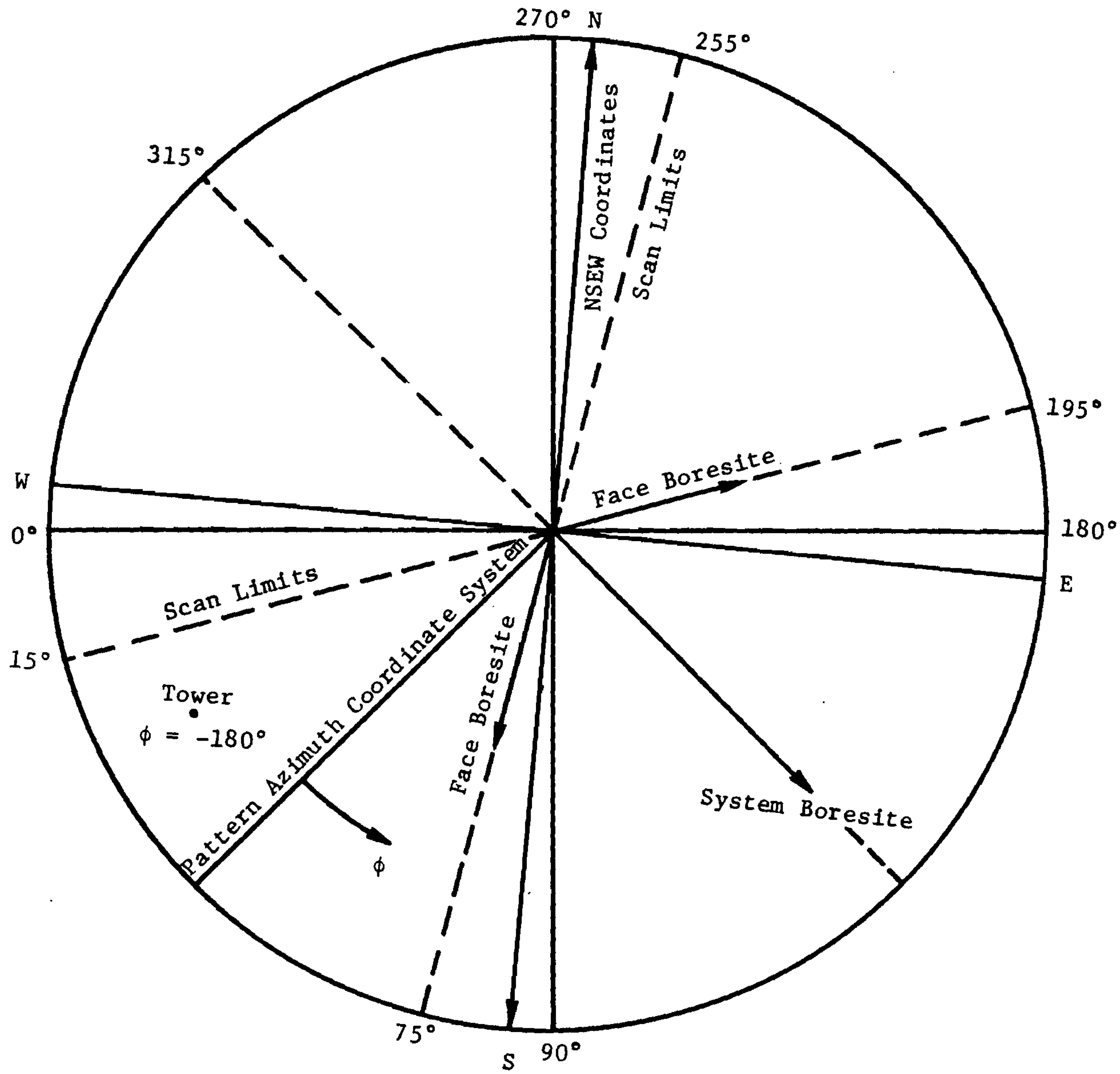


Figure 46. Division of Area Around PAVE PAWS Into Geographical Sectors.

For the area model, the statistical nature of the output could be preselected. The output, given in loss in dB relative to free space, was presented for a given confidence level, reliability, and percent of locations in the area of interest. Loss data were collected at a 50-50-50 level, which means that there is a probability of 0.5 (50%) that the terrain loss in dB, for 50% of the time and 50% of the locations, does not exceed the output value. For each preselected distance from the transmitter, one loss value was obtained. From Equation 8 the field strength was computed, and was given at a probability of 0.5, that is, there was a probability of 0.5 that the true power density was less than the power density given by Equation 8. From these results, for various distances away from the radar site, the field strength in the area was estimated in each of the six sectors surrounding the transmitter at ground level and at top-of-tower level.

For the point-to-point model, the statistical parameter for percent of area was, of course, not present. Also, in this model the explicit terrain elevation values connecting the transmitter and the receiver must be entered. Statistical levels for confidence and percent of time were preselected in this model. Data were collected for the 50-50 level; that is, for 50% of the time, there was a 0.5 probability that the terrain loss would not exceed the output value. Again, Equation 8 was used to compute radiated power levels at various transmitter-receiver locations.

The area model was used to predict the field strength over large geographical areas and these results were used to give an estimate of possible interference to mobile equipment, when combined with appropriate susceptibility data. The point-to-point model, which was the more accurate model, was used to predict field levels at predetermined locations. This was especially useful to predict field strength levels at the repeater tower site.

3.3.3 Field Strength Determination

Once the terrain loss data had been collected, it was combined with the antenna pattern of the radar in order to determine field strength. A computer program was written which was able to integrate into the terrain loss values the effect of the antenna pattern and the gain and output power characteristics of the radar. The standard deviation of the terrain elevation data was input into this program so that a 95% probability window for the resulting field strength levels could be obtained. The average terrain elevation ± 2 standard deviations was used to determine where the program chose to "read" the relative transmitted power level from the analytical form of the antenna pattern. The position on the pattern was determined by computing the observation elevation angle between the transmitter and the observer at the receiving point. Since the observer was assumed to be at a mean elevation, the ± 2 standard deviations allows for most of the possible variations in the actual terrain elevation and the corresponding rise or fall in the field intensity. Since the angle subtended by the observer approached the horizontal as one moved away from the transmitter (i.e., the elevation angle approached zero), and since an angle of 0° lay on a flat portion (filled-in null) of the antenna pattern, the effect was seen only at the close-in distances.

An example output of the Longley-Rice program is shown in Table XI. These results were for the area model at ground level for distances up to 72.4 km from the transmitter. The terrain loss in dB relative to an isotropic radiator is given as a function of distance in km from the transmitter. The difference between the terrain loss value at the 50% confidence level and the free space value is the loss that must be tolerated in order to be 50% sure of achieving contact at the receiver 50% of the time for 50% of the locations in the area. An example output of field strength predictions is shown in Table XII. The field strength in dBm/m^2 and in volts/meter for the 15° - 75° sector surrounding the radar, is given as a function of distance from the transmitter. The ± 2 standard deviations with regard to elevation are also shown. Statistically, these field strength levels were those that at the indicated distance shall not be exceeded with a probability of 0.5, at 50% of the locations, 50% of the time.

Similar example output data for the point-to-point model and the corresponding field strength levels are shown in Tables XIII and XIV.

In this case, the terrain loss is given as a function of height above the ground at a fixed distance from the transmitter. In this example the distance and sector chosen is that of the Georgia Power repeater tower location. The

TABLE XI

EXAMPLE OUTPUT OF LONGLEY-RICE AREA MODEL

ESTIMATED QUANTILES OF BASIC TRANSMISSION LOSS (DB)

DIST KM	FREE SPACE	WITH CONFIDENCE 10.0	50.0	75.0	95.0
1.6	89.4	90.9	101.0	106.3	114.0
3.2	95.4	99.4	109.4	114.7	122.3
4.8	98.9	104.7	114.6	119.8	127.3
6.4	101.4	108.6	118.4	123.5	131.0
8.0	103.3	111.8	121.5	126.6	133.9
9.7	104.9	114.5	124.1	129.2	136.4
11.3	106.3	117.0	126.4	131.4	138.6
12.9	107.4	119.1	128.5	133.5	140.6
14.5	108.4	121.1	130.4	135.3	142.4
16.1	109.4	123.0	132.2	137.0	144.0
17.7	110.2	124.7	133.8	138.6	145.5
19.3	110.9	126.4	135.4	140.1	147.0
20.9	111.6	127.9	136.9	141.6	148.3
22.5	112.3	129.4	138.3	142.9	149.6
24.1	112.9	130.8	139.6	144.2	150.9
25.7	113.4	132.1	140.9	145.4	152.0
27.4	114.0	133.3	141.9	146.5	153.0
29.0	114.5	134.4	142.9	147.5	153.9
30.6	114.9	135.4	143.9	148.4	154.9
32.2	115.4	136.5	144.9	149.4	155.7
33.8	115.8	137.5	145.9	150.3	156.6
35.4	116.2	138.5	146.8	151.2	157.5
37.0	116.6	139.4	147.7	152.0	158.3
38.6	117.0	140.4	148.6	152.9	159.1
40.2	117.3	141.3	149.4	153.7	159.9
41.8	117.7	142.2	150.3	154.6	160.7
43.5	118.0	143.1	151.1	155.4	161.4
45.1	118.3	144.0	152.0	156.2	162.2
46.7	118.6	144.8	152.8	156.9	162.9
48.3	118.9	145.7	153.6	157.7	163.7
49.9	119.2	146.5	154.3	158.5	164.4
51.5	119.5	147.3	155.1	159.2	165.1
53.1	119.7	148.1	155.9	159.9	165.8
54.7	120.0	148.9	156.6	160.7	166.5
56.3	120.2	149.7	157.3	161.4	167.2
57.9	120.5	150.4	158.1	162.1	167.9
59.5	120.7	151.2	158.8	162.8	168.5
61.2	120.9	151.9	159.5	163.5	169.2
62.8	121.2	152.7	160.2	164.2	169.8
64.4	121.4	153.4	160.9	164.8	170.5
66.0	121.6	154.1	161.6	165.5	171.2
67.6	121.8	154.9	162.3	166.2	171.9
69.2	122.0	155.6	163.0	166.9	172.5
70.8	122.2	156.3	163.7	167.6	173.2
72.4	122.4	157.1	164.4	168.3	173.9

TABLE XII

EXAMPLE OUTPUT OF FIELD STRENGTH PREDICTIONS

DISTANCE(KM)	POWER DENS(DBM/M*M)			E(V/M)		
------------	------------------------------			------------------------------		
1.600	22.224	28.398	39.195	7.932E+00	1.615E+01	5.597E+01
3.200	16.642	16.642	22.883	4.171E+00	4.171E+00	8.557E+00
4.800	11.420	11.420	16.735	2.286E+00	2.286E+00	4.216E+00
6.400	7.621	7.621	10.935	1.476E+00	1.476E+00	2.162E+00
8.000	4.483	4.483	5.913	1.029E+00	1.029E+00	1.213E+00
9.700	1.809	1.809	1.809	7.562E-01	7.562E-01	7.562E-01
11.300	-.417	-.417	-.417	5.852E-01	5.852E-01	5.852E-01
12.900	-2.567	-2.567	-2.567	4.569E-01	4.569E-01	4.569E-01
14.500	-4.483	-4.483	-4.483	3.665E-01	3.665E-01	3.665E-01
16.100	-6.192	-6.192	-6.192	3.010E-01	3.010E-01	3.010E-01
17.700	-7.815	-7.815	-7.815	2.497E-01	2.497E-01	2.497E-01
19.300	-9.466	-9.466	-9.466	2.065E-01	2.065E-01	2.065E-01
20.900	-10.958	-10.958	-10.958	1.739E-01	1.739E-01	1.739E-01
22.500	-12.299	-12.299	-12.299	1.490E-01	1.490E-01	1.490E-01
24.100	-13.596	-13.596	-13.596	1.283E-01	1.283E-01	1.283E-01
25.700	-14.954	-14.954	-14.954	1.098E-01	1.098E-01	1.098E-01
27.400	-15.910	-15.910	-15.910	9.832E-02	9.832E-02	9.832E-02
29.000	-16.903	-16.903	-16.903	8.770E-02	8.770E-02	8.770E-02
30.600	-17.970	-17.970	-17.970	7.757E-02	7.757E-02	7.757E-02
32.200	-18.912	-18.912	-18.912	6.959E-02	6.959E-02	6.959E-02
33.800	-19.934	-19.934	-19.934	6.187E-02	6.187E-02	6.187E-02
35.400	-20.835	-20.835	-20.835	5.577E-02	5.577E-02	5.577E-02
37.000	-21.719	-21.719	-21.719	5.037E-02	5.037E-02	5.037E-02
38.600	-22.587	-22.587	-22.587	4.558E-02	4.558E-02	4.558E-02
40.200	-23.440	-23.440	-23.440	4.132E-02	4.132E-02	4.132E-02
48.300	-27.634	-27.634	-27.634	2.549E-02	2.549E-02	2.549E-02
56.300	-31.366	-31.366	-31.366	1.659E-02	1.659E-02	1.659E-02
64.400	-34.933	-34.933	-34.933	1.100E-02	1.100E-02	1.100E-02
72.400	-38.450	-38.450	-38.450	7.339E-03	7.339E-03	7.339E-03
80.500	-41.971	-41.971	-41.971	4.893E-03	4.893E-03	4.893E-03
88.500	-45.294	-45.294	-45.294	3.338E-03	3.338E-03	3.338E-03
96.600	-48.655	-48.655	-48.655	2.267E-03	2.267E-03	2.267E-03
104.600	-51.846	-51.846	-51.846	1.570E-03	1.570E-03	1.570E-03
112.700	-54.994	-54.994	-54.994	1.093E-03	1.093E-03	1.093E-03
120.700	-56.189	-56.189	-56.189	9.521E-04	9.521E-04	9.521E-04

TABLE XIII

EXAMPLE OUTPUT OF LONGLY-RICE POINT-TO-POINT MODEL

```
              DISTANCE          3.1 KM
             FREQUENCY        435.0 MHZ
       ANTENNA HEIGHTS    16.3       6.1 M
     EFFECTIVE HEIGHTS    26.9       6.6 M
      TERRAIN, DELTA H          76. M

     POL=0, EPS= 9., SGM= 0.004 S/M
     CLIM=5, NS=317., K= 1.376
     PROFILE- NP= 14, XI= 0.220 KM

        A SINGLE HORIZON PATH
        DIFFRACTION IS THE DOMINANT MODE

     ESTIMATED QUANTILES OF BASIC TRANSMISSION LOSS (DB)
         FREE SPACE VALUE- 95.0 DB

           RELIA-    WITH CONFIDENCE
           BILITY      5.0    10.0    50.0    75.0    95.0

            10.0      97.2   100.0   110.1   115.3   123.0
            50.0      97.2   100.1   110.1   115.4   123.0
            75.0      97.2   100.1   110.1   115.4   123.0
            90.0      97.2   100.1   110.1   115.4   123.0
```

TABLE XIV

OUTPUT OF FIELD STRENGHT PREDICTIONS
FOR POINT-TO-POINT MODEL

RCVR HT (M)	POWER DENS(DBM/M*M)	E(V/M)
3.048	13.691	2.970E+00
6.096	15.891	3.826E+00
9.144	17.991	4.872E+00
12.192	19.832	6.022E+00
15.240	27.574	1.468E+01
18.290	30.451	2.045E+01
21.340	32.914	2.716E+01
24.380	35.192	3.530E+01
27.430	36.211	3.970E+01
30.480	36.681	4.190E+01
33.530	37.007	4.350E+01
36.580	37.190	4.443E+01
39.620	37.232	4.464E+01
42.670	37.232	4.464E+01
45.720	37.232	4.464E+01
48.770	37.232	4.464E+01
51.820	37.232	4.464E+01
54.860	37.232	4.464E+01
57.910	37.232	4.464E+01
60.960	37.232	4.464E+01
64.010	37.232	4.464E+01
67.060	37.232	4.464E+01
70.100	37.232	4.464E+01
73.150	37.232	4.464E+01
76.200	37.232	4.464E+01
79.250	37.232	4.464E+01
82.300	38.478	5.153E+01
85.340	40.531	6.527E+01
88.390	42.267	7.971E+01
91.440	43.765	9.472E+01
94.490	45.080	1.102E+02
97.540	46.247	1.260E+02
100.580	47.287	1.421E+02
103.630	48.225	1.583E+02
106.680	49.073	1.745E+02

statistical interpretation of the data is the same as for the area model, except that the percent location parameter is not present.

3.3.4 Additional Field Strength Data

At the request of Georgia Tech, the Electromagnetic Compatibility Analysis Center (ECAC) at Annapolis, Maryland, computed field strengths for the area surrounding the RAFB radar site. ECAC has a large data-base on the topography of the area which provides much more detailed and accurate contour data than is possible to collect from contour maps. ECAC also has extensive data on other topographical parameters for central Georgia, such as refractivity, dielectric constants, etc. This data base was used to generate power density contours using TIREM (Terrain Integrated Rough Earth Model), a point-to-point ECAC propagation model. The propagation loss values computed by this program were comparable to the Longley-Rice Area model at the 50-50-50 statistical level described earlier. Field strengths were computed at elevations of 3 m and 105 m (105 m is the top-of-tower height of the Georgia Power repeater tower). Copies of the results were presented to both Georgia Tech and Georgia Power in the form of transparent overlays onto maps of fixed field strength contours with 10 dBm/m^2 spacings between the contours.

Figure 47 shows the ECAC-generated contours at a 3 m elevation. Superimposed on the figure are circles showing the radii predicted by the Longley-Rice Area Model for field strength levels of -15, -25, -35 and -45 dBm/m^2. These circles are not intended to be correct in the backlobe region but are given simply to show the relationship between the ECAC-generated contours and the Longley-Rice area model contours in the main sweep area.

Figure 48 gives similar results for the 105 m elevation.

In both figures the radii of the circles of the Longley-Rice area model represent the distance outside of which there is a probability of 0.5 that for 50% of the locations the field strength level will not exceed the indicated power level 50% of the time.

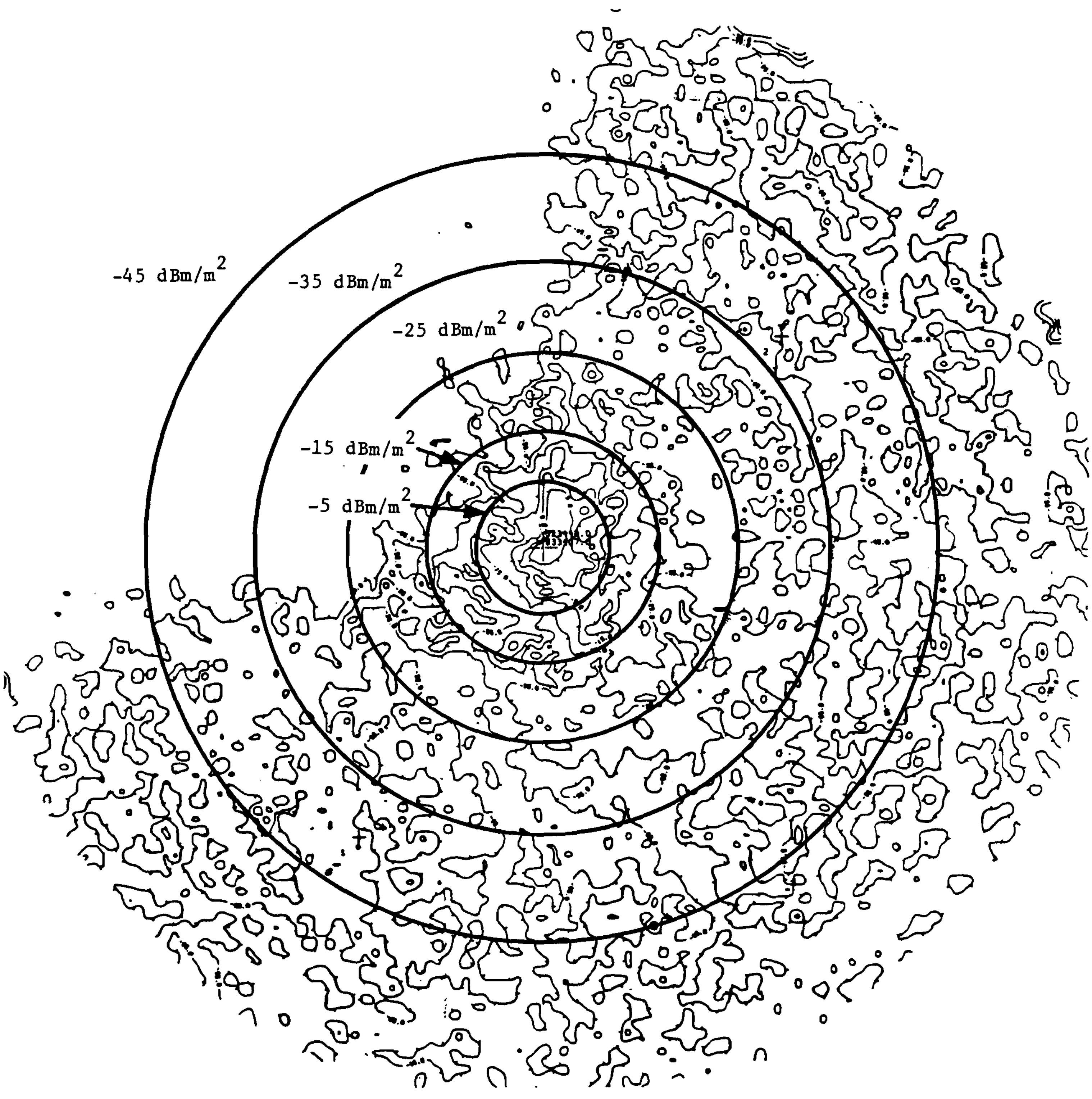


Figure 47. ECAC-Generated Field Strength Contours with Superimposed Longly-Rice Area Model Curves--Ground Level.

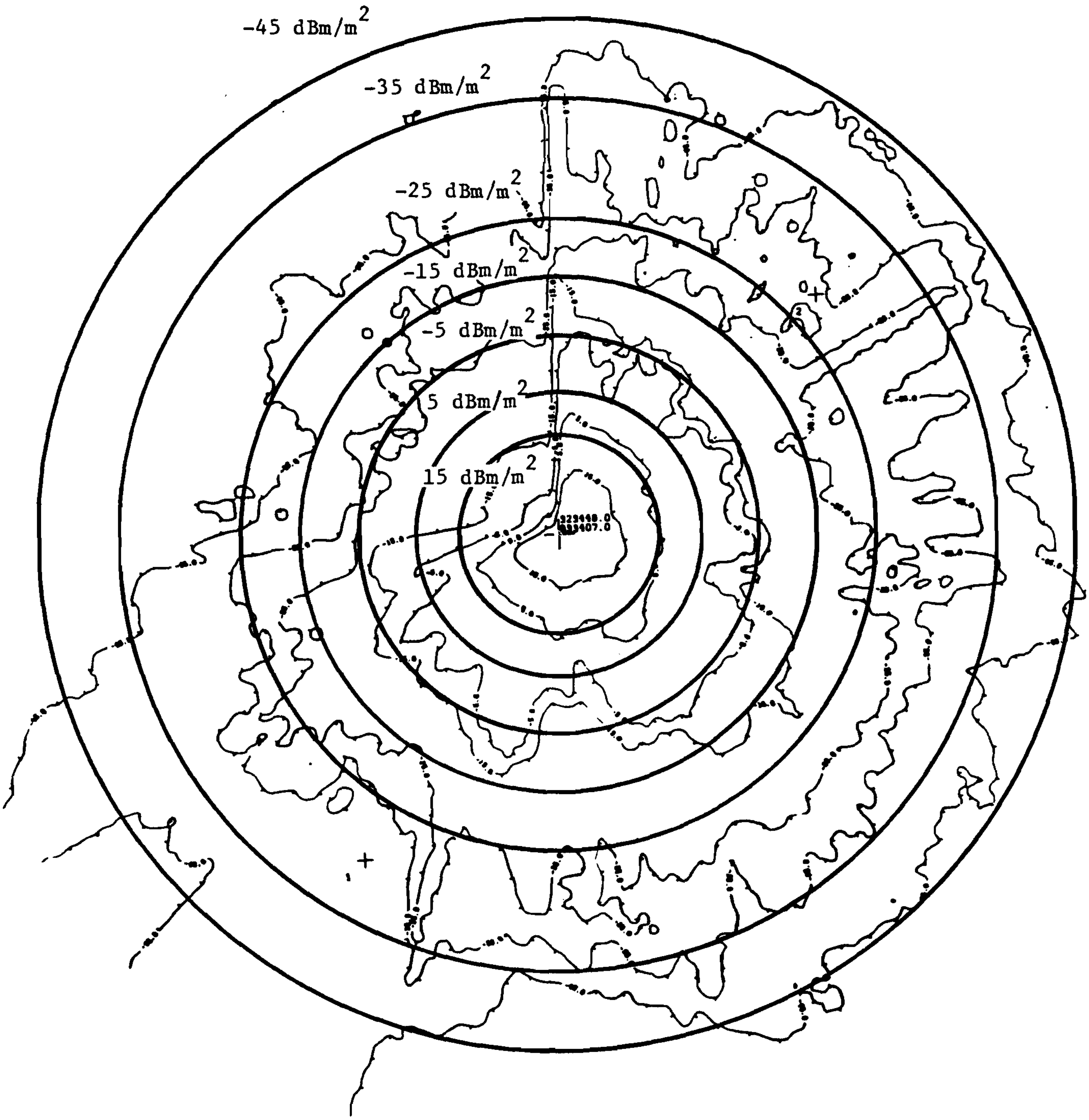


Figure 48. ECAC-Generated Field Strength Contours with Superimposed Longley-Rice Area Model Curves--Top-of-Tower Level.

From the ECAC-generated contours it is easy to see that, outside the predicted boundary, the field strengths may, at some locations, exceed the indicated level. This is due to the fact that the Longley-Rice model is based on statistical terrain data, whereas the ECAC model is based on explicit terrain data.

For further analysis, either of the two sets of contours could be used. Although the ECAC model gives more detailed data with respect to terrain, the Longley-Rice model may be more useful because it eliminates the complexity of the detailed contours and provides a simple method to estimate field strength. Thus, the analysis presented in the following sections will utilize the results of the Longley-Rice model.

4. INTERFERENCE ASSESSMENTS

4.1 General

The measured susceptibility data given in Section 2 and the predicted field strength levels of Section 3 provide a basis for identifying potential interference problems caused by the PAVE PAWS radar. To identify potential problems, measured susceptibility thresholds are simply compared to predicted field intensity levels. If the predicted field strengths are higher than reciever susceptibility thresholds, then interference is highly likely. If the field strengths are below the susceptibility thresholds, then the potential for interference is low.

Because of differences in operating characteristics or deployment conditions, the test specimen UHF and microwave receivers were divided into three categories for purposes of interference assessments. The first category contains those land mobile UHF receivers (SYNTOR, MICOR, Base Station, Handi-Talkies, and associated antennas) which are operated near ground level and whose location with respect to the PAVE PAWS site will be highly variable. The second category contains the UHF repeater and antenna, which will generally be installed at a fixed tower site. Interference assessments of the repeater receiver must address both case-coupled interference and interference coupled to the receiver via the tower mounted antenna. The third category contains the microwave receiver and multiplexer. Since this receiver uses a waveguide input, case-coupled interference is of primary concern, since the interference frequency (420 - 450 Mhz) is well below the wave guide cutoff frequency.

4.2 UHF Land Mobile Equipment

The worst-case susceptibility threshold for the mobile UHF receivers (SYNTOR, MICOR, Base Station, and Handi-Talkies) was found to be approximately -39 dBm/m^2 (Section 2.6). The region around the PAVE PAWS radar site for which the field strength levels met or exceeded -39 dBm/m^2 was determined analytically using the Longley-Rice area model described in Section 3.3. These results are shown in Figure 49.

The curved boundary corresponding to -39 dBm/m^2 in the main sweep area has a radius of approximately 73 km (45.6 miles). The backlobe distance corresponding to the same power density level is approximately 27 km (16.9 miles). Although the total area surrounding the transmitter was divided into six sectors of 60^o extent each, as previously described, the radius of the curved boundary corresponding to a power density level of -39 dBm/m^2 was virtually the same for each sector in the main sweep area. Outside the curved boundaries the field strength is expected to be less than -39 dBm/m^2 and in those regions the mobile equipment is expected to suffer no interference.

In the four sectors into which the main beam is transmitted, the power density level was computed in a straight-forward manner as described in Section 3.3. The two remaining sectors outside the main sweep area will be referred to as the "backlobe" area. The estimates for the field levels in these two sectors were calculated in the following way: When the PAVE PAWS radar is transmitting at either of the extreme sweep angles, then the first, second, third and higher order sidelobes radiate into the two backlobe sectors. The two sectors encompass an area subtending an angle of 120^o, and so the minimum field strength level should occur 60^o away from the scan limits into the backlobe area. In order to estimate this minimum field strength level, the analytical form of the radar's antenna pattern was generated with the main beam aimed along the horizontal at an extreme sweep angle (Figure 50). As the figure shows, at 3^o away from the main beam, the field strength

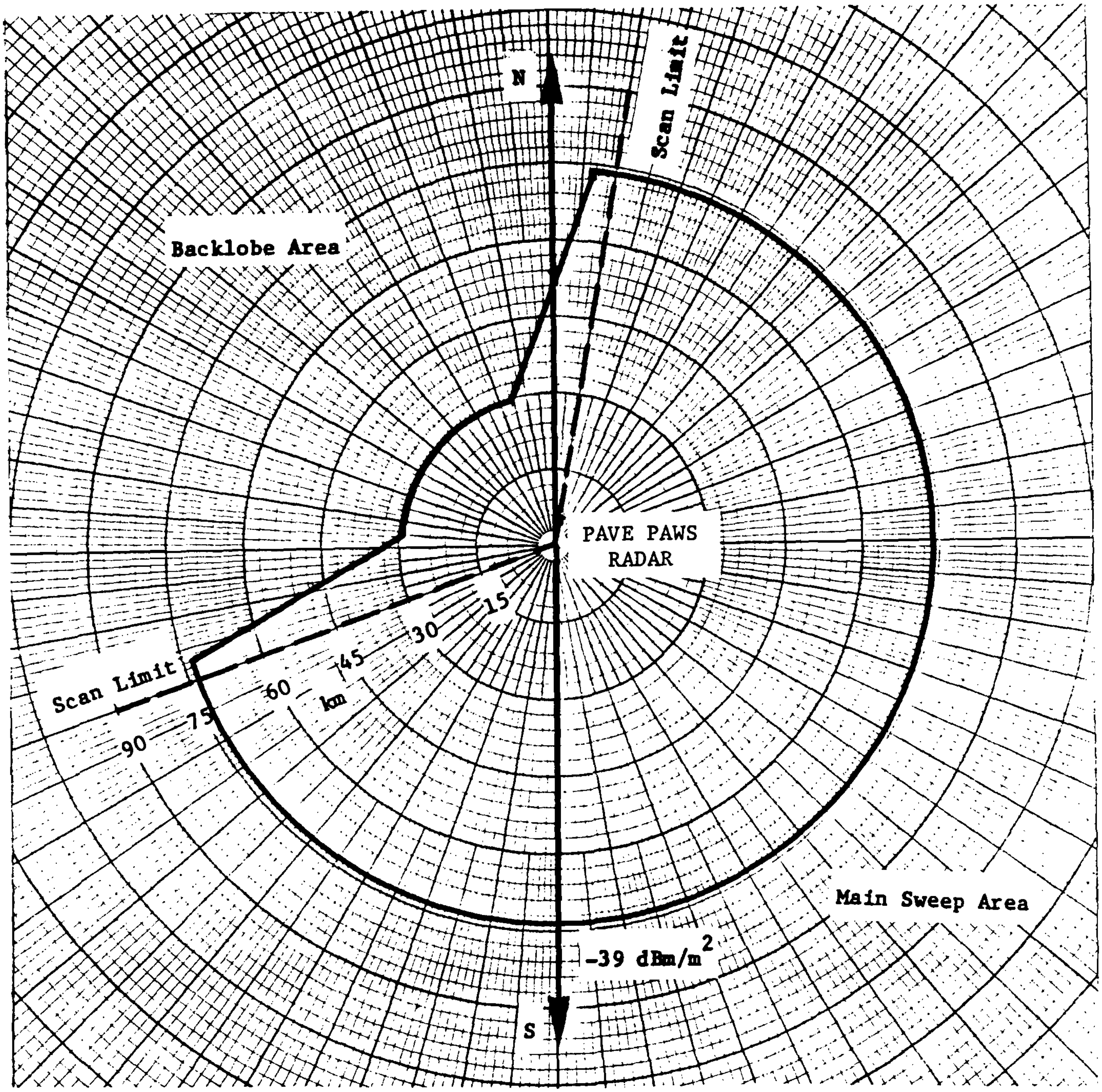


Figure 49. Predicted -39 dBm/m^2 Field Strength Contour in Area Around PAVE PAWS.

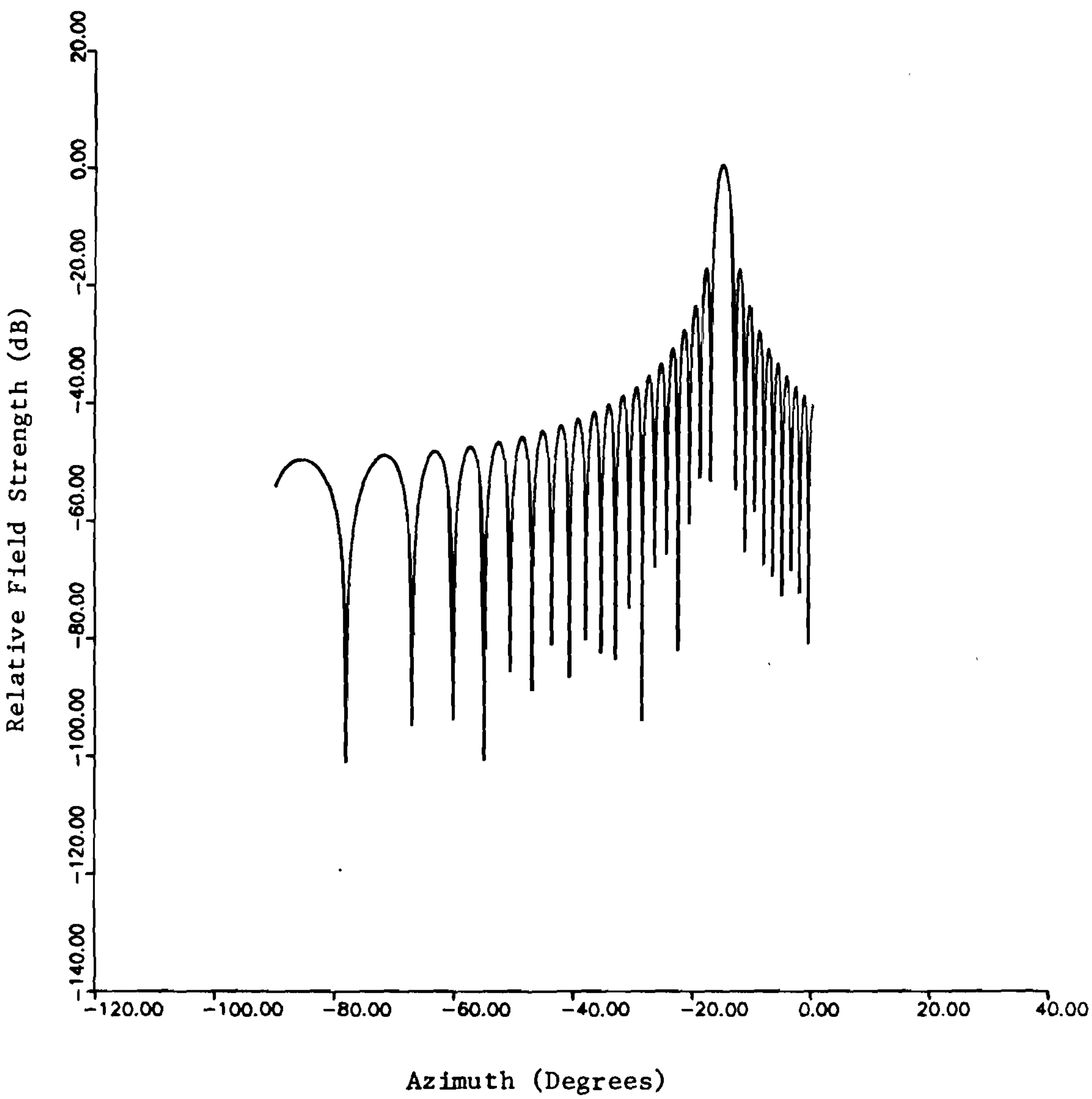


Figure 50. PAVE PAWS Radar Antenna Pattern When Main Beam is at the Extreme Sweep Angle -- Azimuth Cut.

has dropped approximately 22 dB, and at 60^{o} away from the main beam has dropped to a level approximately 50 dB below that of the main beam. The difference between these two levels, 28 dB, represents the maximum field strength that will exist in a direction 180^{o} from the system boresite, which conforms to the worst-case philosophy. However, these field strength levels are a result of the mathematical form of the radar pattern. Discussions with the Air Force Electronic System Division indicate that the actual minimum backlobe field strength level for the PAVE PAWS radar will be approximately -45 dBm/m^2. Thus, the backlobe level is approximately 23 dB below the 3^{o} point. The field strength profile throughout the two-sector backlobe region is given relative to the main beam by the envelope of the analytical form of the antenna pattern down to a level of -45 dBm/m^2 -- after which a constant level of -45 dBm/m^2 is assumed.

Figure 49, then, represents the contour outside of which the field strength is less than -39 dBm/m^2 for the entire 360^{o} region surrounding the PAVE PAWS site. The field strength in the 120^{o} backlobe region was calculated for a worst-case condition.

The confidence level corresponding to the contour is 0.5, and the percent of locations and percent of time is given at the 50-50 level, respectively. This means that, for a receiver outside the contour, there is a probability of 0.5 that for 50% of the locations and 50% of the time the field strength will not exceed -39 dBm/m^2.

This contour is smooth because it is statistically based, and it averages the true -39 dBm/m^2 contour, which would show variations according to changes in the terrain. Of course, this means that outside the contour the field strength may exceed -39 dBm/m^2 at some locations some of the time. In a similar manner, there may be areas inside the contour for which the field strength is less than -39 dBm/m^2 some of the time. However, on the average, the field strength outside the contour will be below the susceptibility level of the mobile receiver.

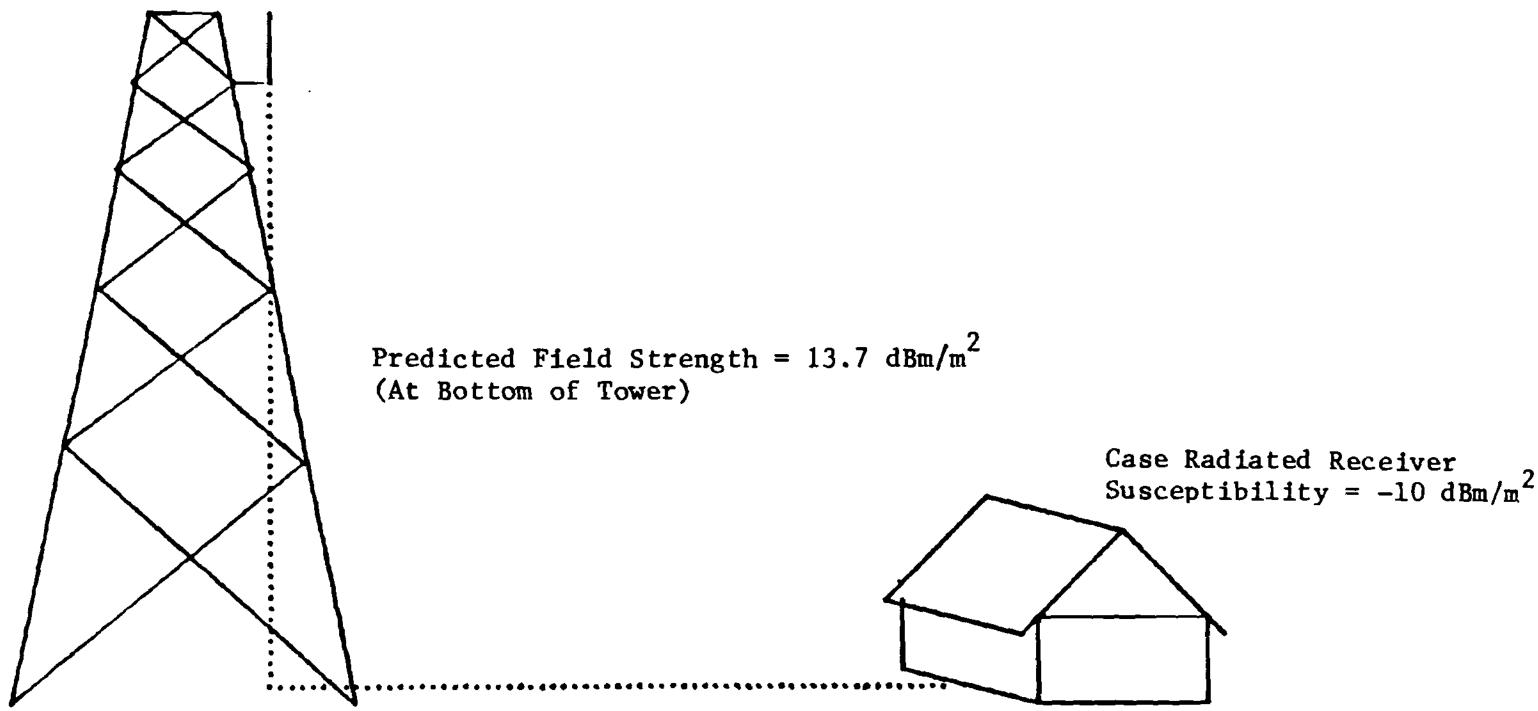


Figure 51. Case Radiated Interference Assessment for UHF Repeater.

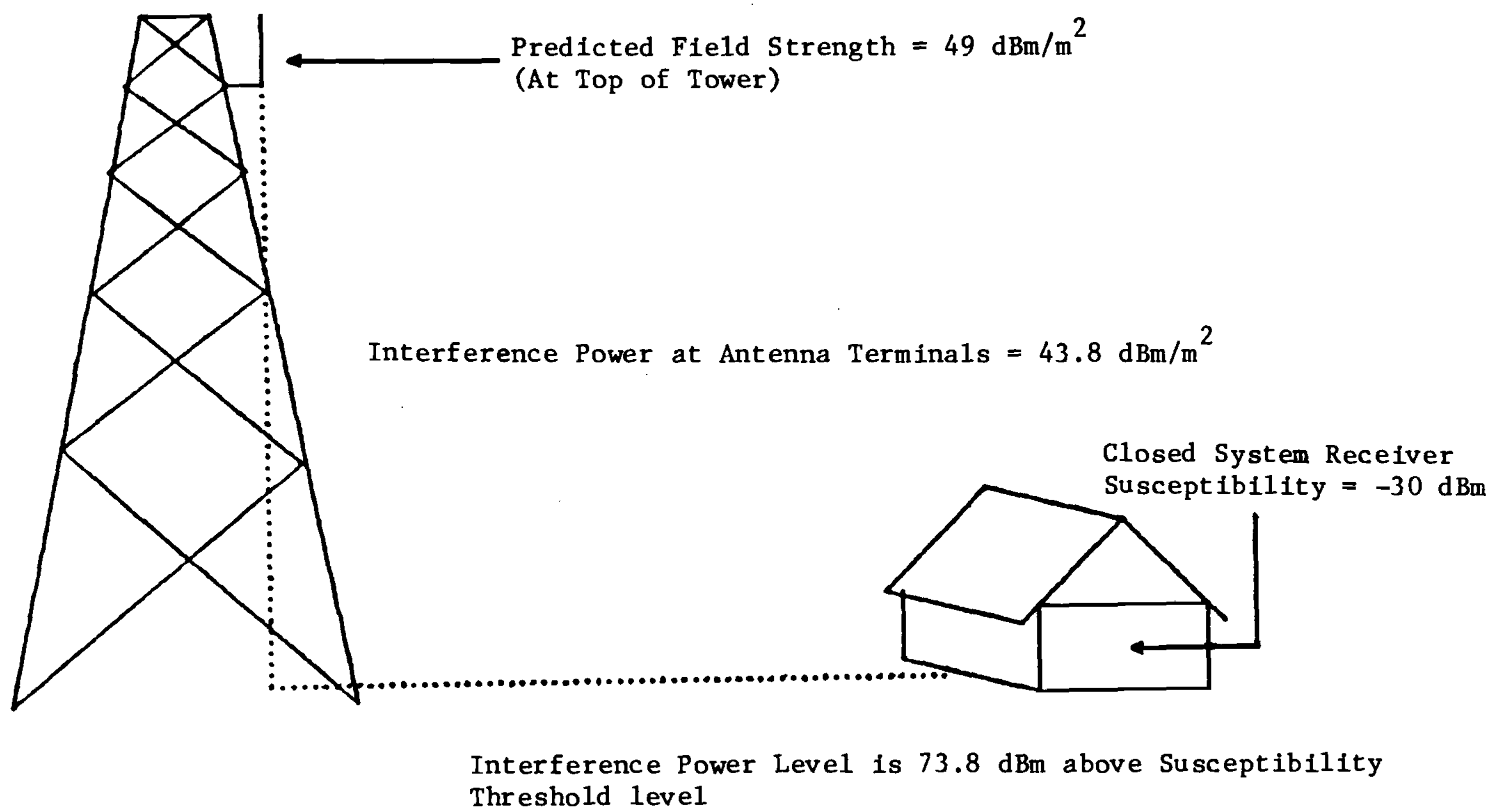


Figure 52. Antenna Conducted Interference Assessment for UHF Repeater.

4.3 UHF Repeater

The interference conditions which will exist for the UHF repeater when the PAVE PAWS system becomes operational are illustrated in Figures 51 and 52. Figure 51 indicates the potential for interference to the receiver due to case radiated interference signals whereas Figure 52 defines interference conditions caused by pickup of the interference signal via the tower mounted repeater antenna.

As noted in Figure 51, the predicted field strength at the bottom of the tower will be 13.7 dBm/m^2 (from Section 3.3). If no shielding is provided by the building which houses the repeater equipment, then the receiver will be exposed to this field strength.

From the data of Table IV, note that the minimum case-radiated susceptibility threshold recorded on the repeater is -10 dBm/m^2 (at the image response). A comparison of this threshold with the predicted field strength shows that the field strength is 23 dB above the threshold level. Thus, corrective actions may be necessary to eliminate case-radiated interference to the repeater, depending upon the shielding provided by the building which houses the receiver. Additional shielding could be provided either to the building or to the receiver case.

The assessment of interference conditions which exist due to antenna conducted interference is illustrated in Figure 52. In this assessment, an antenna gain and cable loss, respectively, of 10 dB and 1 dB were assumed. It is understood from Georgia Power that these values are representative of the antenna and cable characteristics which are used in the repeater installation.

Using the predicted field strength (+49 dBm/m^2) at the repeater antenna and the above values of antenna gain and cable loss, the interference signal power (in dB) at the antenna terminals of the repeater receiver is calculated from

$$P_r = FS + G_r + 20 \log(\lambda) - 10 \log(4\pi) - L \qquad (11)$$

where P_r = Power at antenna terminals (dB),

G_r = Repeater antenna gain (dB),

FS = Field Strength (dBm/m^2),

λ = Wavelength (0.69 meters at 435 MHz), and

L = Cable loss (dB).

Inserting the respective values gives

$$P_r = 49 + 10 + 2(-0.16) - 11 - 1 = 43.8 \text{ dBm.} \tag{12}$$

From Table II it is noted that the minimum, closed-system susceptibility threshold for the repeater is approximately -30 dBm. When this threshold level is compared to the predicted +43.8 dBm interference power input, it is seen that the peak interference power at the receiver antenna terminals is approximately 74 dB above the receiver interference threshold. Even at lower PAVE PAWS frequencies, Figure 20 shows that the antenna conducted susceptibility threshold of the repeater does not exceed approximately -5 dBm. Thus at any PAVE PAWS frequency, the interference injected into the receiver via the antenna terminals will exceed the measured susceptibility threshold by not less than 49 dB. These calculations show that the repeater receiver will likely experience severe antenna conducted interference problems when the PAVE PAWS radar becomes operational. This problem will not be simple to resolve because of the small difference between the PAVE PAWS and receiver operating frequencies. The antenna and cable will offer no rejection to the PAVE PAWS signal, and filters which pass the desired signal (456.125 MHz) and provide 74 dB of rejection to the interference signal (449.2 MHz) are not readily available.

4.4 Microwave Receiver/Multiplexer

The interference conditions for the microwave receiver and multiplexer are illustrated in Figure 53. The threshold levels shown on the figure are for the receiver/multiplexer test configuration, since this configuration represents worst-case conditions. Note that since a wave guide transmission line is used, case-radiated interference will be of primary concern.

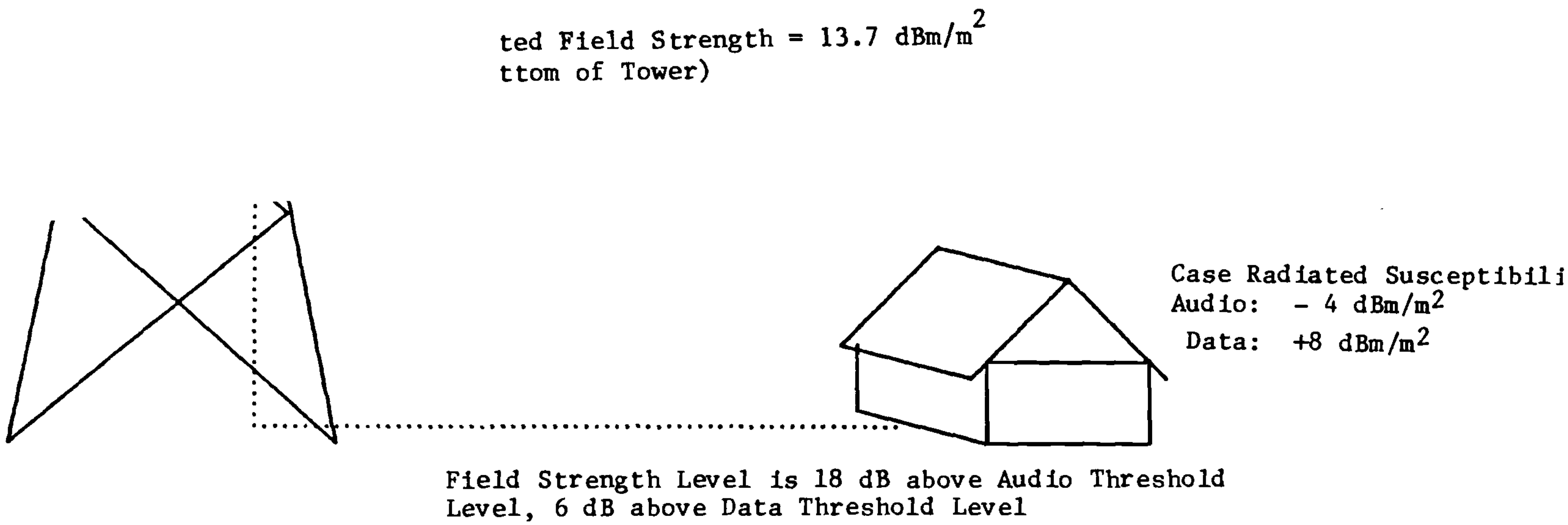


Figure 53. Case Radiated Interference Assessment for Microwave Receiver and Multiplexer.

TABLE XV

WORST-CASE SUSCEPTIBILITY THRESHOLDS
FOR MICROWAVE RECEIVER AND MULTIPLEXER

Test Configuration	Worst-Case Thresholds (dBm/m^2)	
	Audio	Data
Receiver Alone	+15	+39
Receiver/Multiplexer	-4	+8

As indicated in Section 2.3.4, the worst-case (adjusted) case-radiated thresholds which were measured are shown in Table XV. When the threshold levels in this table are compared to the predicted field strength of +14 dBm/m^2 at the base of the tower, it is seen that for the receiver alone test configuration, both the audio and data thresholds are above the predicted field strength -- 1 dB above for audio and greater than 25 dB above for the data signal. Hence the likelihood of audio interference is marginal whereas the possibility of interference to the data signal is considered remote.

For the receiver/multiplexer test configuration, Table XV shows that both the audio and data thresholds are below the predicted field strength. The audio threshold is 18 dB below and the data threshold is 6 dB below. Under these conditions, it is likely that interference to both the audio and data signals will occur.

The above interference conditions are based on the assumption that the building which houses the microwave receiver and multiplexer provides no shielding agains the PAVE PAWS signal. If the building had a shielding effectiveness of 18 - 20 dB, then the incident field strength would be reduced to a value which was below the receiver/multiplexer audio and data thresholds.

5. MITIGATION METHODS

5.1 General

The interference assessments of Section 4 indicate that the Georgia Power Company UHF and microwave communications systems will experience interference problems when the RAFB PAVE PAWS system becomes operational. The following paragraphs outline possible actions which can be taken to mitigate these problems. For convenience, discussions of mitigation methods are divided into the same three test specimen equipment categories which were used for interference assessments, namely: (1) UHF land mobile receivers (SYNTOR, MICOR, Base Station, Handi-Talkies, and associated antennas), (2) UHF repeater and antenna, and (3) microwave receiver and multiplexer.

The discussions of mitigation methods which follow are intended only to identify possible approaches to resolving the potential interference problems identified in Section 4. Before specific corrective actions can be taken, several technical and cost issues must be addressed and resolved. One issue involves the criteria for what constitutes "acceptable" interference. If it is desired that the communication systems operate without any detection of the radar pulse, then mitigation methods must be applied which raise the susceptibility thresholds of the test specimen equipment above the existing field strength levels created by PAVE PAWS. An approach typically employed to minimize the possibility of interference is to raise the threshold levels above incident field strength levels by some "safety factor" (typically 10 dB). The safety factor is used to account for possible unknown or unpredictable variations in interference conditions (variations in propagation and terrain characteristics, equipment susceptibility thresholds, etc.).

If some degree of interference is acceptable, then mitigation requirements can be relaxed. For example, it might be decided that audio interference to the UHF land mobile equipment could be tolerated at a "nuisance" level so long as it did not seriously affect the communications process. Such a decision might be an acceptable trade-off between the technical and cost impact of achieving a "no interference" condition based on worst-case interference assessments. Note that the interference assessments of Section 4 were based on worst-case susceptibility thresholds. Figures 22 through 30 illustrate that these worst-case thresholds occur only at the higher PAVE PAWS frequencies and at spurious response frequencies. Because the PAVE PAWS system is scanned in frequency, these worst-case frequencies will occur only a small percentage of the time. Furthermore, the radar beam is scanned in space, which further reduces the time that worst-case interference conditions will exist. Hence, thresholds could possibly be "raised" (e.g., 5 - 10 dB) above those worst-case levels used for interference assessments without a severe increase in receiver interference (except at intermittent intervals corresponding to spatial/frequency scanning conditions of the radar). The above comments are not intended as a recommendation that mitigation requirements be relaxed, but rather to point out that this option exists and should be addressed.

Another issue to be resolved will involve investigations of the technical characteristics of the various methods that can be employed to mitigate interference problems. It is fairly easy to identify applicable mitigation methods, yet practical engineering solutions cannot be identified until the specific merits and limitations of each method is well defined. For example, an obvious approach to substantially reducing interference to the UHF receivers would be to simply change the receiver operating frequencies. That is, move the operating frequencies further away from the PAVE PAWS frequency band. From a practical viewpoint, such and approach may be totally unacceptable either because of technical limitations or cost considerations. Even if a frequency change could be easily accommodated, investigations would be necessary to determine the benefits of such a change. Furthermore, note that the application of several mitigation methods may be required for adequate interference suppression. Thus, trade-off investigations must be performed to define those combinations of mitigation methods which will provide the maximum amount of interference rejection at the least cost.

Finally, mitigation methods which are applied must be compatible with system operational requirements. Any conflicts between system requirements and mitigation methods must be identified and resolved. If such conflicts arise, it may be advantageous to accept some change or degradation in system performance if this change is accompanied by a significant reduction in interference problems.

5.2 UHF Mobile Receivers

The mitigation of interference effects in the UHF mobile receivers will be more difficult than the resolution of interference problems in the UHF repeater and microwave receivers, for a number of reasons. One reason is that due to receiver mobility requirements, mitigation methods must accommodate a wide range of interference conditions. A second reason is that the receivers will likely be required to operate at locations where the interference field strength is considerably higher than the worst-case susceptibility threshold which was measured. As noted in Figure 49, interference free operation would be realized only if the receivers were always operated beyond a distance of approximately 73 kilometers from the PAVE PAWS site. Operational requirements will likely require that the receivers operate much closer to the site, perhaps even on-site. Figure 54 shows how the field strength decreases as the distance from the site decreases. A third reason involves the number of receivers which will be affected. If many receivers are involved, the design and implementation of mitigation techniques on each receiver could be very costly. Finally, because the mobile receivers are constructed in fairly compact form, mitigation methods which are conceptually sound may be difficult to implement in practice.

Prior to discussing specific mitigation methods, it is informative to try to "visualize" the interference effects which will occur when the mobile receivers are exposed to the PAVE PAWS signal. Note from figures 22 - 24 and Figures 29 and 30 that for PAVE PAWS frequencies which fall at receiver spurious responses or near the upper frequency limit the susceptibility thresholds are fairly low (worst-case threshold is -39 dBm/m^2). At other frequencies, the worst-case threshold is approximately -10 dBm/m^2. Hence, between these two field intensity limits, interference effects will be intermittent rather than continuous because of frequency scanning. Furthermore, even at worst-case frequencies, interference effects will be intermittent because the radar antenna beam is being spatially scanned and the receiver will not be continuously exposed to worst-case field strengths. Thus, a receiver which is exposed to such interference conditions will experience interference only a small percentage of time. Even if the -10 dBm/m^2 threshold were exceeded, interference effects would still be intermittent due to spatial scanning. This discussion is not intended to recommend that interference to the mobile receivers be tolerated, but rather to provide information helpful to making trade-off decisions.

Several methods for mitigating interference effects in the mobile receivers are outlined below. The decision to apply any particular method or combination of methods will involve a trade-off between operational requirements, the "degree" of acceptable interference effects, and cost.

Location/Distance

If operational requirements did not dictate that the mobile receivers be located within a 73 kilometer radius of the PAVE PAWS site, then the problem of mitgating interference effects in the receivers would be resolved. If the receivers are to be operated within this radius and no other mitigation methods are applied, then the interference effects to be expected can be roughly surmised from the susceptibility data of Figures 22, 23, 24, 29, and 30 and the field intensity versus distance plot of Figure 54.

One possibility of minimizing interference effects within the 73 kilomter radius would be to locate a point on the terrain (e.g., in a valley or behind a hill) where the field strength was relatively low. The field strength contours provided by the Electromagnetic Compatibility Analysis Center (ECAC) could be used to locate such points. A potential problem with such an approach is that the desired signal level may be lowered because of the particular location selected. As noted in Figure 13, a decrease in desired signal level is usually accompanied by a decrease in the susceptibility threshold.

Frequency Change

It has been noted earlier (Section 2.5.3) that at the higher PAVE PAWS frequencies where the susceptibility thresholds are the lowest the UHF receivers are simply responding to the spectral characteristics of the PAVE PAWS signal. Thus one method for increasing the susceptibility threshold of the mobile receivers would be to change their operating frequencies. For example, note from Figure 30 that if the tuned frequency of the HT-220 HANDI-TALKIE were shifted upward by approximately 6 MHz, the worst-case susceptibility threshold (excluding spurious responses) would increase from approximately -39 dBm/m^2 to -10 dBm/m^2. The increase in frequency separation between the PAVE PAWS and receiver frequencies would also make it easier to suppress receiver spurious responses. Any changes in receiver operating frequencies would require investigations to identify and obtain FCC approval of desired frequencies and to ensure the change did not result in other undesired interference effects (e.g., other spurious responses).

Filtering

The use of bandpass filters tuned to a receiver's operating frequency can be an effective means of reducing out-of-band interference, particularly spurious responses. For example, a bandpass filter tuned to 451.2 MHz which

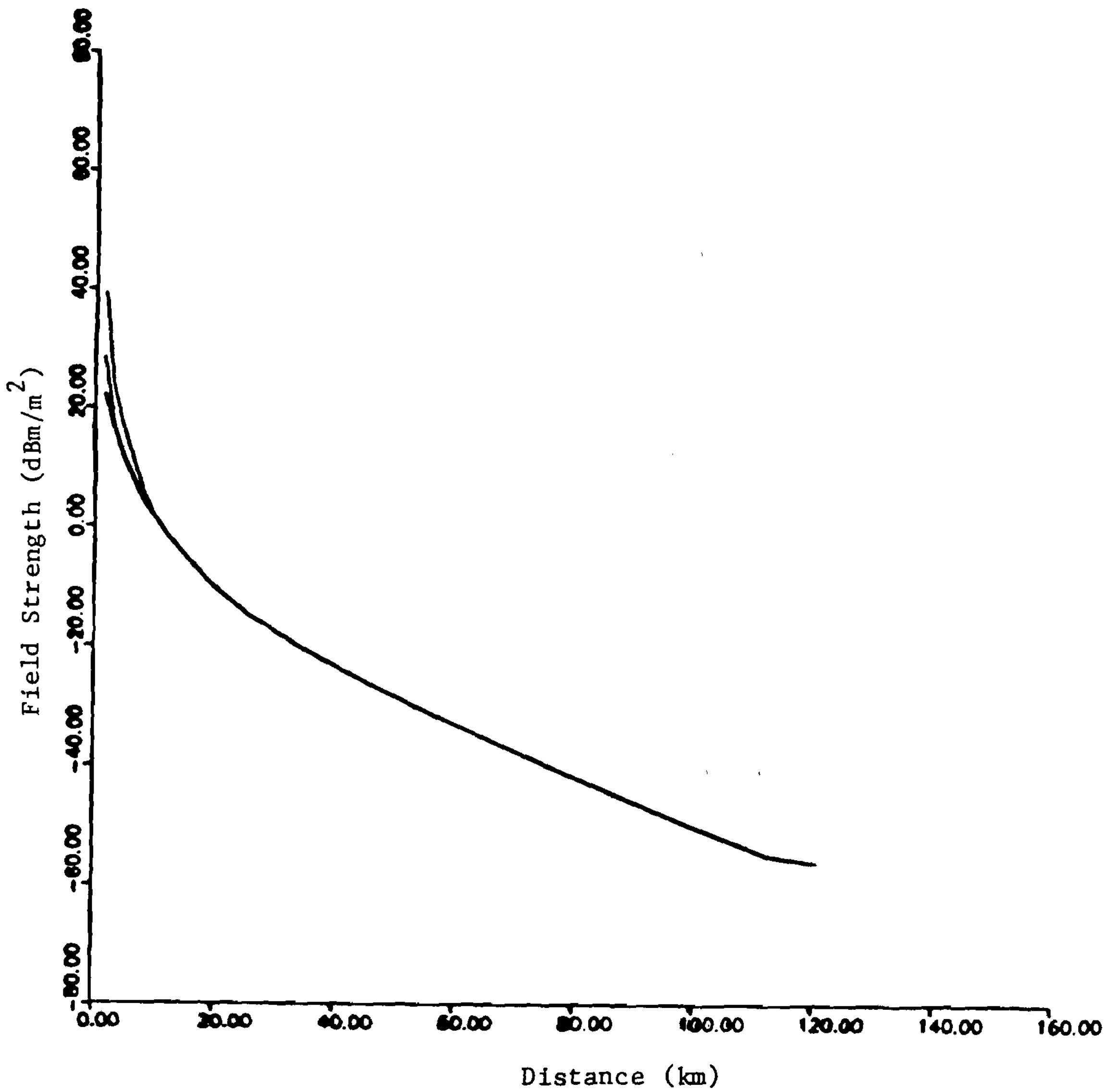


Figure 54. Ground Level Variation in Predicted Field Strength versus Distance from PAVE PAWS Site -- 190^{o} - 250^{o} Sector.

provided a rejection of 35 dB to signals 22 MHz away from the filter's center frequency would essentially "remove" the spurious response from the data of Figure 24 (assuming adequate case shielding).

Because of the compact configuration of the mobile receivers, the application of filters presents a somewhat difficult design task. For the SYNTOR, MICOR, and Base Station receiver, external filters could probably be employed. For the HANDI-TALKIES, internal modifications to the receiver front-ends would be required. The design of the filters would require a compromise between desired rejection characteristics and filter size (obviously, large cavity filters could not be used). Note that the filter designs would be easier if the difference between the spurious response frequencies and the receiver's tuned frequency were larger; i.e., if the receiver's tuned frequency were shifted upward.

It should be evident that improved front-end filtering will only affect the receiver spurious responses. Receiver susceptibility thresholds resulting from in-band interference will not be changed, i.e., they will still be responsive to the PAVE PAWS spectrum.

Shielding

In section 2.6 (Figure 25 - 27), it was noted that some of the incident energy was coupled to the mobile receivers via the receiver case. Hence it is evident that some improvement in the shielding effectiveness of the receiver cases will be required. The specific amount of shielding required will depend upon the improvements made in the receiver's rejection to spurious responses and in-band energy. Extensive efforts to improve case shielding would not be warranted if the receivers susceptibility to interference is dictated by these two interference mechanisms.

5.3 UHF Repeater

The mitigation of interference effects in the UHF repeater will require that both case radiated and antenna conducted interference problems be addressed. Case-radiated problems should be relatively simple to resolve by shielding the building which houses the repeater. As noted in Section 4, the predicted field strength at the repeater location is 23 dB above the radiated susceptibility thresholds of the repeater. This assessment assumes that the present building provides no shielding against the incident field. In practice, a shielding effectiveness of considerably greater than 23 dB is relatively easy to achieve. Structures which provide 60 -100 dB of shielding are commonly designed and configured for military applications, although they are costly. Thus, case-radiated interference problems in the UHF repeater could be readily resolved through a properly shielded building.

The interference assessment of potential antenna conducted interference problems showed that the predicted interference power at the repeater antenna terminals is 73 dB above the worst-case susceptibility threshold. A combination of several mitigation methods may be required to reduce the interference power below threshold (or to an "acceptable" level above threshold). Investigations of, and trade-offs between, various mitigtaion methods will be necessary to define an optimum solution which is compatible with system operational requirements. Several methods to be considered are outlined below.

Height of Repeater Antenna

Figure 55 shows the variation in predicted field strength as a function of height above ground level at the tower location. From this figure it is evident that lowering the antenna from its present location on the tower would bring about a decrease in the field strength to which the antenna will be exposed. Obviously, any change in antenna height would have to be compatible with system operational requirements.

Location of Repeater Antenna

If the receiver antenna were moved further away from the radar site (by relocating the tower), then the field strength at the UHF antenna would be reduced due to the increase in distance (at a rate of 20 log R, or 6 dB per octave) and to the effective reduction in antenna height relative to the PAVE PAW antenna pattern. Figure 56 illustrates the fall-off in field strength as a function of distance for tower locations within the scan angle of the radar

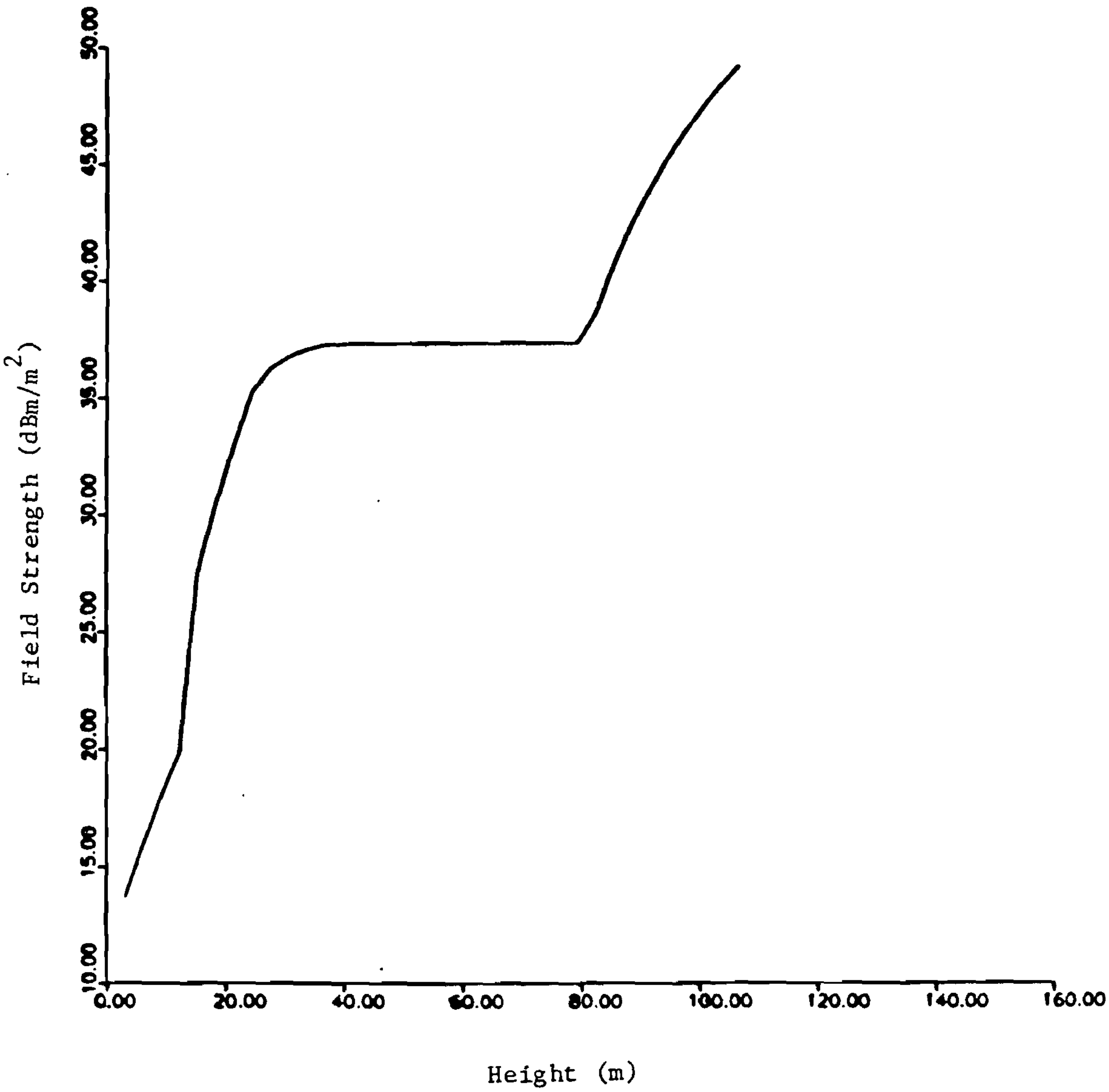


Figure 55. Variation in Predicted Field Strength versus Height Above Ground at Present Tower Location.

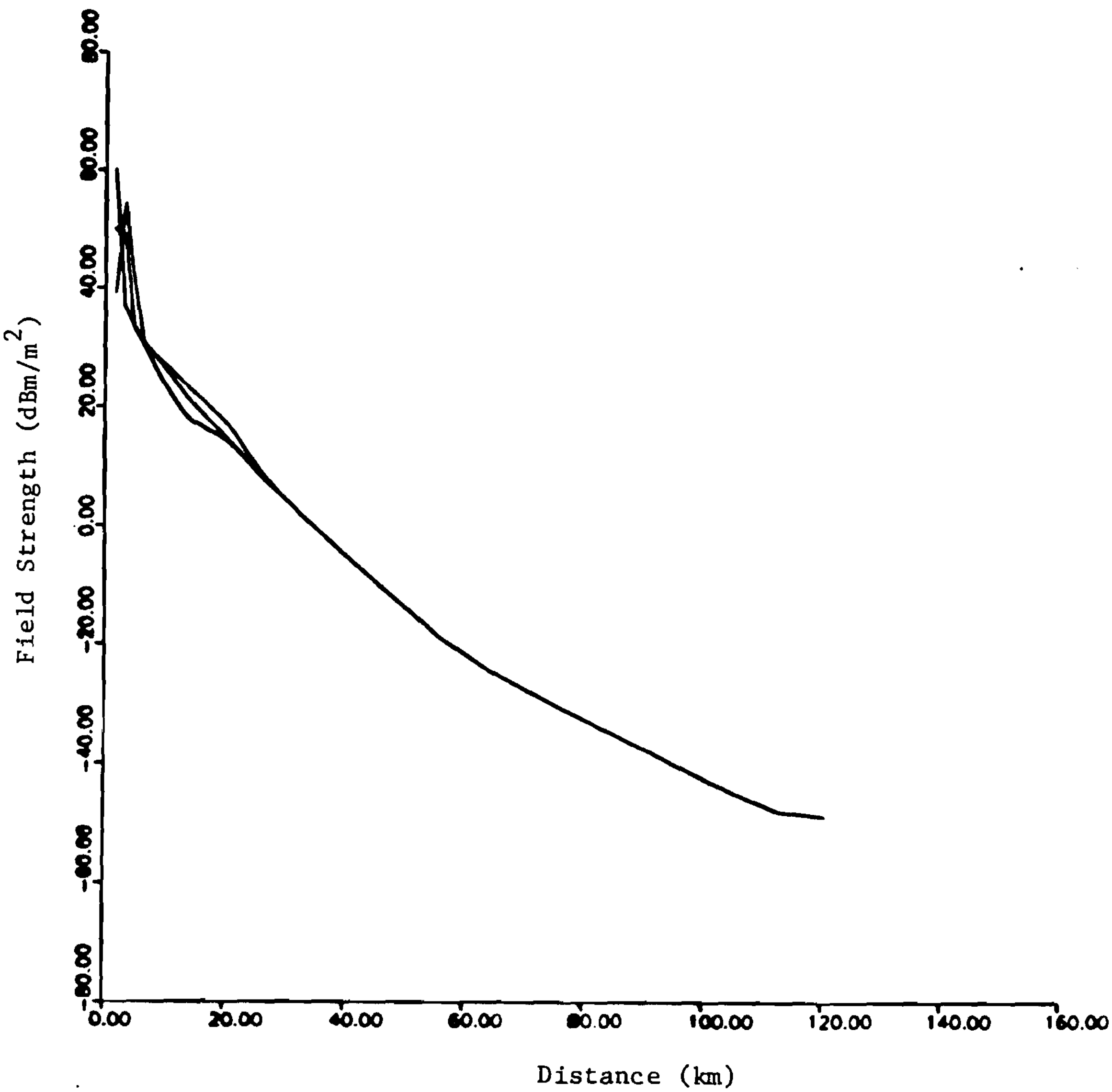


Figure 56. Top-of-Tower Variation in Predicted Field Strength versus Distance from PAVE PAWS Site.

antenna pattern. These data in this figure are for a constant antenna height above ground level.

It is also evident that locating the tower/UHF antenna in the backlobe of the radar would reduce the level of the field incident on the UHF antenna, even if the distance from the radar remained the same. Any movement of the antenna, whether in distance or orientation with respect to the PAVE PAWS site, would have to satisfy the UHF repeater operational requirements.

Transmission Line Filters

The frequency difference between the UHF repeater tuned frequency (456.125 MHz) and the upper PAVE PAWS frequency at band edge (449.2 MHz) is approximately 7 MHz. This small frequency difference poses a major challenge in filtering out the interference signal. Transmission line filters which will pass the desired signal (with low insertion loss) and provide greater than 73 dB of rejection to the interference signal may not be readily available as off-the-shelf items. However, it is certainly possible to design cavity filters which will provide this amount of rejection. Georgia Tech has a double tuned UHF cavity filter (Collins Model 56C-2) which, when tuned near 400 MHz, has a 3 dB bandwidth of approximately 300 kHz, an insertion loss of less than 1 dB, and will provide greater than 50 dB rejection to a signal which is 7 MHz away from the tuned frequency. The cascading of three or more cavities should allow a rejection level of 73 dB to be realized.

Change in Repeater Operating Frequency

As shown in Figure 20, the susceptibility threshold of the repeater is a minimum (-30 dBm) at the highest PAVE PAWS frequency (449.2 MHz). As the interference frequency is decreased, the threshold increases until a limit of approximately -8 dBm is reached near 444 MHz. The characteristics of these data imply that if the tuned frequency of the repeater were increased by 5 MHz to 461.125 MHz, then the susceptibility curve of Figure 20 would also be shifted upward in frequency by 5 MHz. If such were the case, then the minimum susceptibility threshold (at 449.2 MHz) would be -8 dBm, rather than -30 dBm.

The above example points out the possibility of alleviating interference in the UHF repeater through a change in operating frequency. Care would have to be exercised to ensure that any frequency change did not produce additional interference problems (e.g. spurious responses). Also, possible difficulties in obtaining approval for different operating frequencies, the cost impact of a change in frequency, and other factors would have to be considered before a frequency change was made.

Antenna Pattern Control

Different repeater antenna configurations and patterns could be used to reduce antenna pickup of the interference signal. For example, two antennas with controlled patterns could be employed, located directly across the PAVE PAWS site from one another. The pattern of each antenna would roughly approximate a semi-circle, with the primary radiation pattern oriented away from PAVE PAWS and the backlobe or null directed toward the PAVE PAWS site. The two antennas operating together would provide essentially a 360° coverage in azimuth for UHF mobile system operation, yet provide a reduction in gain to the PAVE PAWS signal. Since this approach would require a second antenna and tower, its merits would have to be weighted against the additional costs.

A second approach would be to use a single antenna with a pattern null in the direction of PAVE PAWS. The null would have to be relatively sharp to prevent a major loss in pattern coverage. The success of this approach would depend upon the capability for either purchasing or designing an antenna with the desired pattern characteristics. It is conceivable that a second, highly directive antenna could be employed to produce the pattern null.

5.4 Microwave Receiver and Multiplexer

In terms of the need to mitigate potential interference problems, the microwave communications system is considered to be the more critical system because of its use for data transmission. On the other hand, the interference assessments indicate that potential problems with this system will not be particularly severe and that their resolution should be relatively straightforward. No interference pickup via the antenna and waveguide transmission line is anticipated (with the possible exception noted below) and the worst-case radiated susceptibility threshold is only 18 dB below the predicted field intensity level. This assessment is based on the assumption that the building which houses the receiver and multiplexer provides no shielding against the incident PAVE PAWS signal. However, it is likely that the building as presently constructed will provide some shielding, probably in the range of 5 - 25 dB. Furthermore, the upgrade of this building to provide a much higher shielding effectiveness should be readily achievable. Building designs which have shielding effectiveness values of 60 - 100 dB are commonly employed. Hence, it is concluded that potential interference problems to the microwave equipment can be mitigated simply through an improvement in the shielding of the structure which houses the equipment.

The above noted exception involves harmonics of the PAVE PAWS system which may fall within the operating frequency band of the microwave system. For instance, the 15th harmonic of signals in the 420 - 450 MHz frequency band would fall in the 6300 - 6750 frequency band. Similarly, the 16th harmonic would fall in the 6720 - 7200 frequency band. Since these bands encompass the operating frequencies of the microwave receivers, the possibility of co-channel interference problems in the microwave receivers due to harmonic frequencies can not be totally excluded.

Because the power radiated at the harmonics of the PAVE PAWS fundamental frequency is not known, accurate interference assessments of harmonically related interference problems cannot be performed. However, it is expected that the probability of such problems occurring will be very low, for the following reasons. First, harmonic suppression for PAVE PAWS is specified to be at least 90 dB (referenced to the power at the fundamental frequencies) as indicated in Table VIII. Since the power in a harmonic generally decreases as the harmonic number increases, the higher order harmonics (e.g., 14th, 15th, and 16th harmonics) should be suppressed much more than 90 dB. Second, the gain of the PAVE PAWS antenna at 6.5 GHz is likely to be considerably less than the gain at the 420 - 450 MHz design frequency. Finally, the directivity of the microwave system antennas will provide rejection of signals which do not arrive directly on or very near antenna boresight.

Although data is not available to perform accurate interference assessments, it is informative to assign numerical values to the above assumptions. For instance, assume that the 16th harmonic of the PAVE PAWS signal is a potential source of interference, and that the peak power of this harmonic is 100 dB below the power at the fundamental frequency. Further assume that the PAVE PAWS antenna gain at this harmonic is 20 dB below that value which was used in Section 3 to predict the field intensity (+49 dBm/m^2) at the top of the microwave tower. Under these assumptions, the field intensity of the 16th harmonic at the top of the tower would be -71 dBm/m^2 (+49 dBm/m^2 - 100 dB - 20 dB).

The nominal gain of the antennas used with the microwave system is 42 dB. For this gain, the half-power beamwidth is approximately 1.4 degress. Thus even a few degrees difference between the boresight of these antennas and the PAVE PAWS site location will cause a significant reduction in the antenna gain to PAVE PAWS signals. If a 15 dB gain reduction is assumed, then the off boresight antenna gain would be +27 dB. The interference power input to the microwave receiver can then be approximated as

$$P_r = FS + G_r + 20 \log (\lambda) - 10 \log (4\pi) \quad (13)$$

$$= -71 + 27 - 27 - 11$$

$$= -82 \text{ dBm.}$$

As noted previously, the microwave receiver is typically operated with a desired signal level of -32 dBm. The above estimate indicates that the harmonic power into the receiver will be 50 dB below the desired signal level. Although data are not available to substantiate this numerical estimate, it appears reasonable. For this reason, major efforts to mitigate harmonically related interference problems are not considered to be warranted unless additional information or data indicate otherwise.

6.0 CONCLUSION AND RECOMMENDATIONS

This report presents the results of investigations performed to identify, and to suggest possible approaches for resolving, interference problems to Georgia Power communication systems which may arise when the PAVE PAWS radar at Robins Air Force Base becomes operational. The major findings and conclusions drawn from the program investigations are outlined below.

The results of the interference susceptibility measurements performed on the test specimen UHF and microwave system components can be summarized as follows:

(1) The UHF receivers are susceptible to both antenna-conducted and case radiated signals. Because of its waveguide transmission line, the microwave receiver is likely to be susceptible only to case-radiated interference (at the radar fundamental frequency). Although not substantiated, estimates indicate that PAVE PAWS harmonics which fall at the tuned frequency of the microwave receiver will not be of sufficient magnitude to cause interference problems.

(2) In the UHF receivers, interference from the PAVE PAWS signal may be caused by the pickup of spectral components in the receiver passband, by spurious responses, or by high power effects. Worst-case interference conditions occur for frequencies which are either near the receiver tuned frequency or at receiver spurious response frequencies.

(3) Variations in the pulse width and pulse repetition frequency of the interference signal had little effect on the susceptibility thresholds of the test specimen UHF receivers. This result is to be expected since these parameters do not significantly affect the spectral characteristics of the signal which are removed (by a few MHz) from the signals' center frequency. No effects of chirp width changes were noted except for a "broadening" in spurious response frequency ranges.

(4) For the microwave receiver alone test configuration, minimum interference susceptibility thresholds were obtained with maximum interference signal pulse width settings. Variations in pulse repetition frequency had little effect on the threshold levels. Conversely, in the receiver/multiplexer test configuration, pulse width variations had no significant effect on interference thresholds, whereas changes in pulse repetition frequency caused significant variations in threshold levels. Minimum thresholds occurred at low pulse repetition frequencies. No effects of chirp width variations were noted for either test configuration.

(5) The worst-case radiated susceptibility threshold measured on the mobile UHF receivers (SYNTOR, MICOR, Base Station, and Handi-Talkies) was approximately -39 dBm/m^2.

(6) For the UHF repeater, the worst-case case-radiated susceptibility threshold measured was approximately -9 dBm/m^2. The worst-case antenna-conducted susceptibility threshold was -30 dBm.

(7) The worst-case audio susceptibility threshold recorded on the microwave receiver was +15 dBm/m^2. For the receiver alone test configuration, no interference to the data signal was noted.

(8) For the microwave receiver/multiplexer test configuration, the worst-case audio threshold which was measured was -4 dBm/m^2. The worst-case data threshold was +8 dBm/m^2.

The analytical predictions of the electromagnetic environment created by PAVE PAWS yielded the following results:

(1) At the top of the tower on which the UHF repeater antenna is located, the predicted field strength levels is +49 dBm/m^2.

(2) At the building which houses the UHF repeater receiver and microwave system components, the predicted field strength is +14 dBm/m^2.

(3) For the mobile UHF receivers, the distance from the PAVE PAWS site at which the predicted field strength is equal to the worst-case susceptibility threshold is approximately 73 kilometers.

From the susceptibility data and the predicted field strength levels, the following interference assessments can be made:

(1) The interference signal power at the UHF repeater antenna terminals due to pickup via the repeater antenna terminals will be approximately 74 dB above the worst-case antenna-conducted susceptibility threshold of the repeater receiver. This large difference between the interference power level and the receiver susceptibility threshold indicates a severe interference problem.

(2) The field strength at the UHF repeater receiver location is 23 dB above the worst-case case-radiated susceptibility threshold of the receiver. Thus even without consideration of antenna conducted interference problems, the repeater receiver will likely suffer interference problems from case-radiated signals.

(3) For the microwave receiver and multiplexer, the predicted field strength is 18 dB and 6 dB, respectively, above the worst-case audio and data thresholds. Case-radiated interference problems are thus likely to occur.

(4) Interference to the UHF mobile receivers is likely to occur if the receivers are operated within a radius of 73 kilometers of the radar site.

Several methods for mitigating interference effects in the UHF and microwave systems were identified. These methods involve changes in the location and height of the repeater tower, changes in the operating frequencies of the UHF land mobile network, pattern control of the UHF repeater antenna, shielding, filtering, etc. The proper application of the methods should substantially reduce interference effects in the UHF repeater and microwave receiver/multiplexer. Interference to the UHF land mobile receivers will be more difficult to resolve because of their mobility requirements and because their compact design configuration inhibits the application of interference suppression techniques and devices.

Several issues must be addressed prior to selecting any mitigation method or combination of methods. Criteria for what constitutes "acceptable" interference must be established, the technical characteristics, merits, and limitations of the various mitigation methods must be defined, possible tradeoffs or conflicts between mitigation methods and system operational requirements must be resolved, and cost factors must be identified.

7.0 REFERENCES

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3. Sidney J. Everett, et. al., "Southeast PAVE PAWS: Environmental Assessment," Report USAFSAM-TR-83-7, SRI International, Menlo Park, California, March 1983.

4. Paul D. Newhouse, "A Simplified Method for Calculating the Bounds on the Emission Spectra of Chirp Radars (Revised Edition)," ESD-TR-81-100, Electromagnetic Compatibility Analysis Center, Anapolis, Maryland, August 1982.

5. The Longley-Rice Model--An Implementation, Programmers and User's Guide, National Telecommunications and Information Administration, Institute for Telecommunication Sciences, 1979.

APPENDIX A

EFFECTS OF PULSE REPETITION FREQUENCY
ON SUSCEPTIBILITY THRESHOLDS
RECEIVER ALONE TEST CONFIGURATION

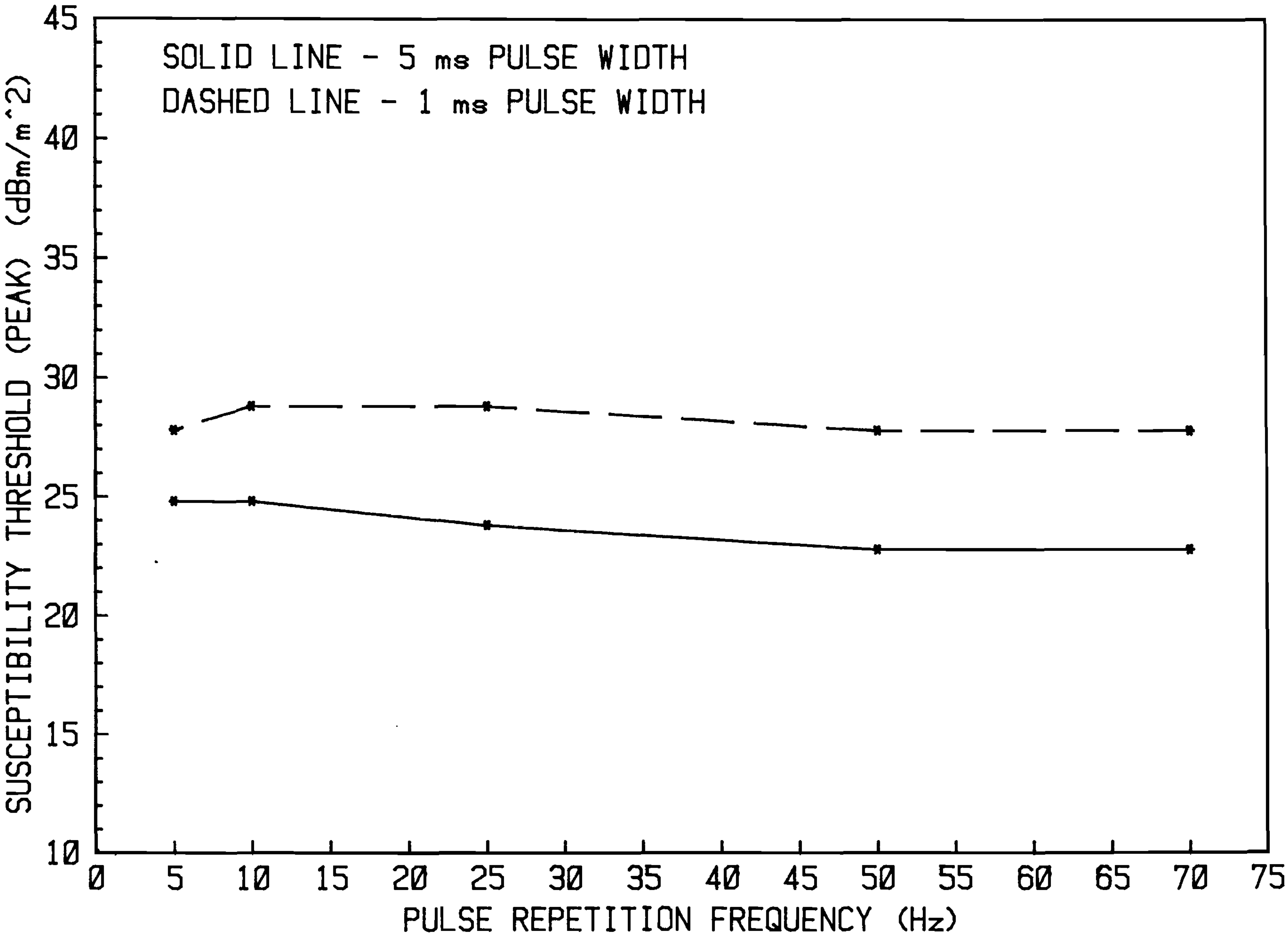

Figure A-1. Radiated Susceptibility Thresholds versus Pulse Repetition Frequency for Receiver Alone -- Channel G1 (4 - 8 kHz).

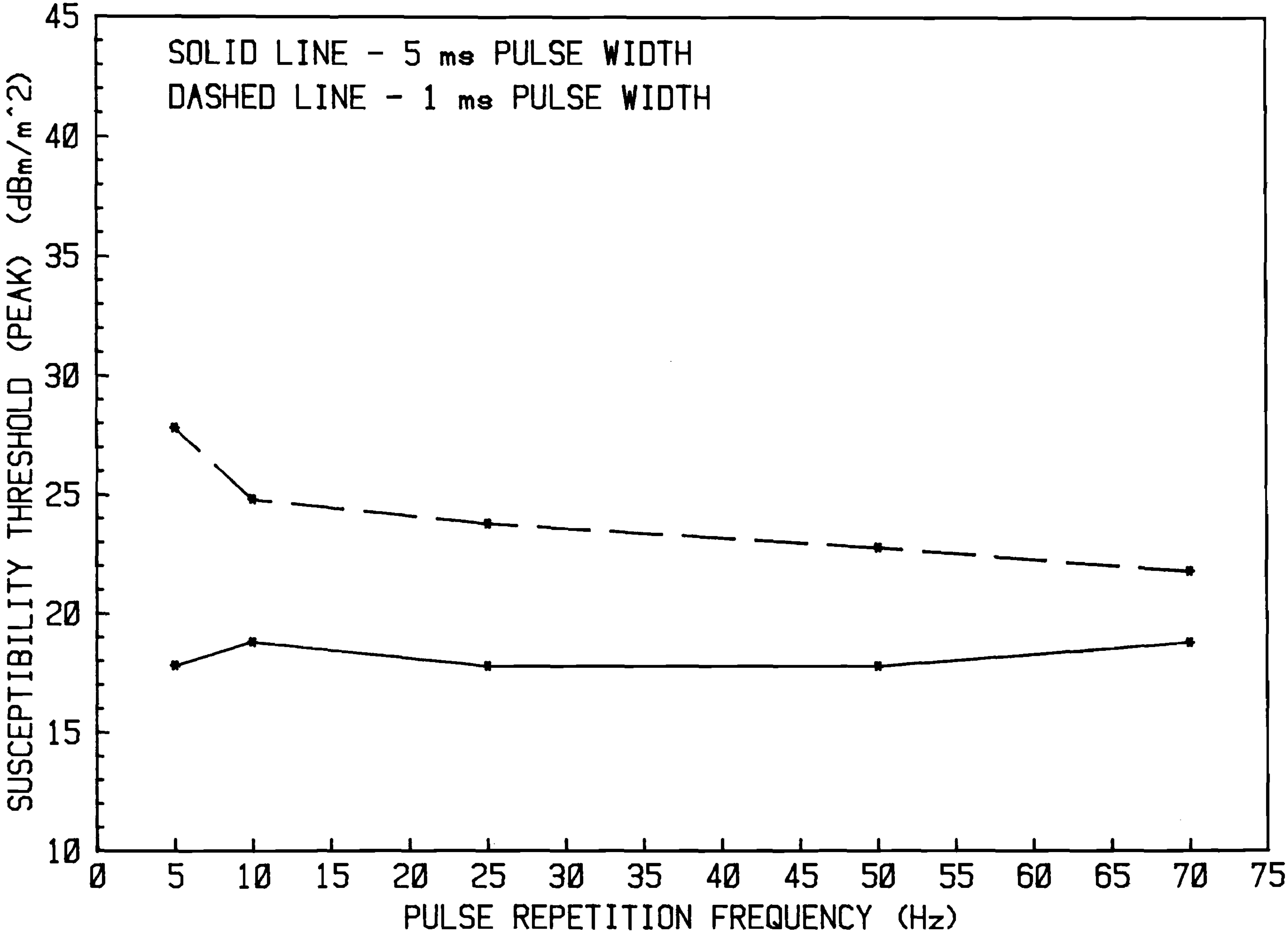

Figure A-2. Radiated Susceptibility Thresholds versus Pulse Repetition Frequency for Receiver Alone -- Channel 1-5-12 (60 - 64 kHz).

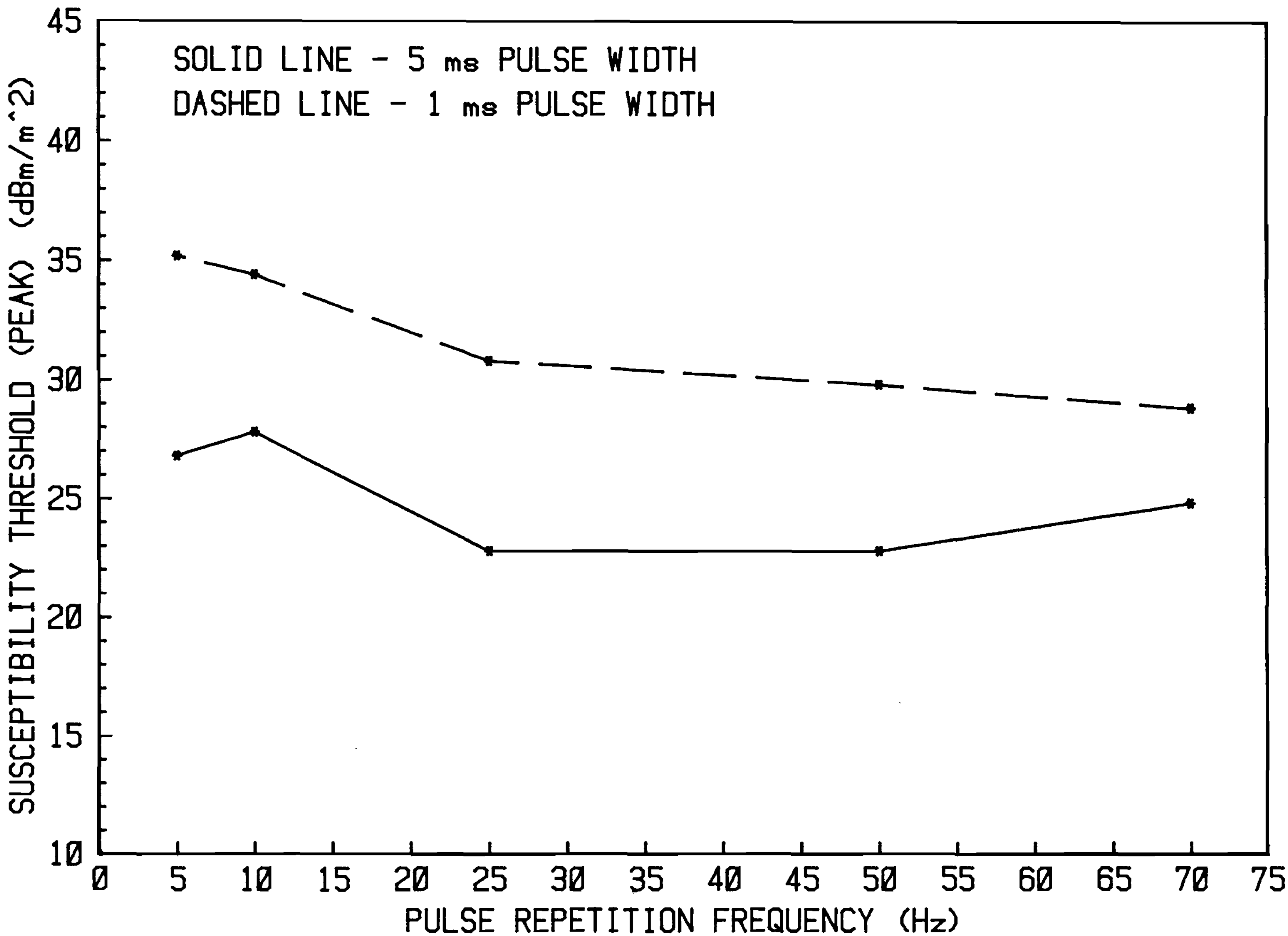

Figure A-3. Radiated Susceptibility Thresholds versus Pulse Repetition Frequency for Receiver Alone -- Channel 5-2-1 (1248 - 1252 kHz).

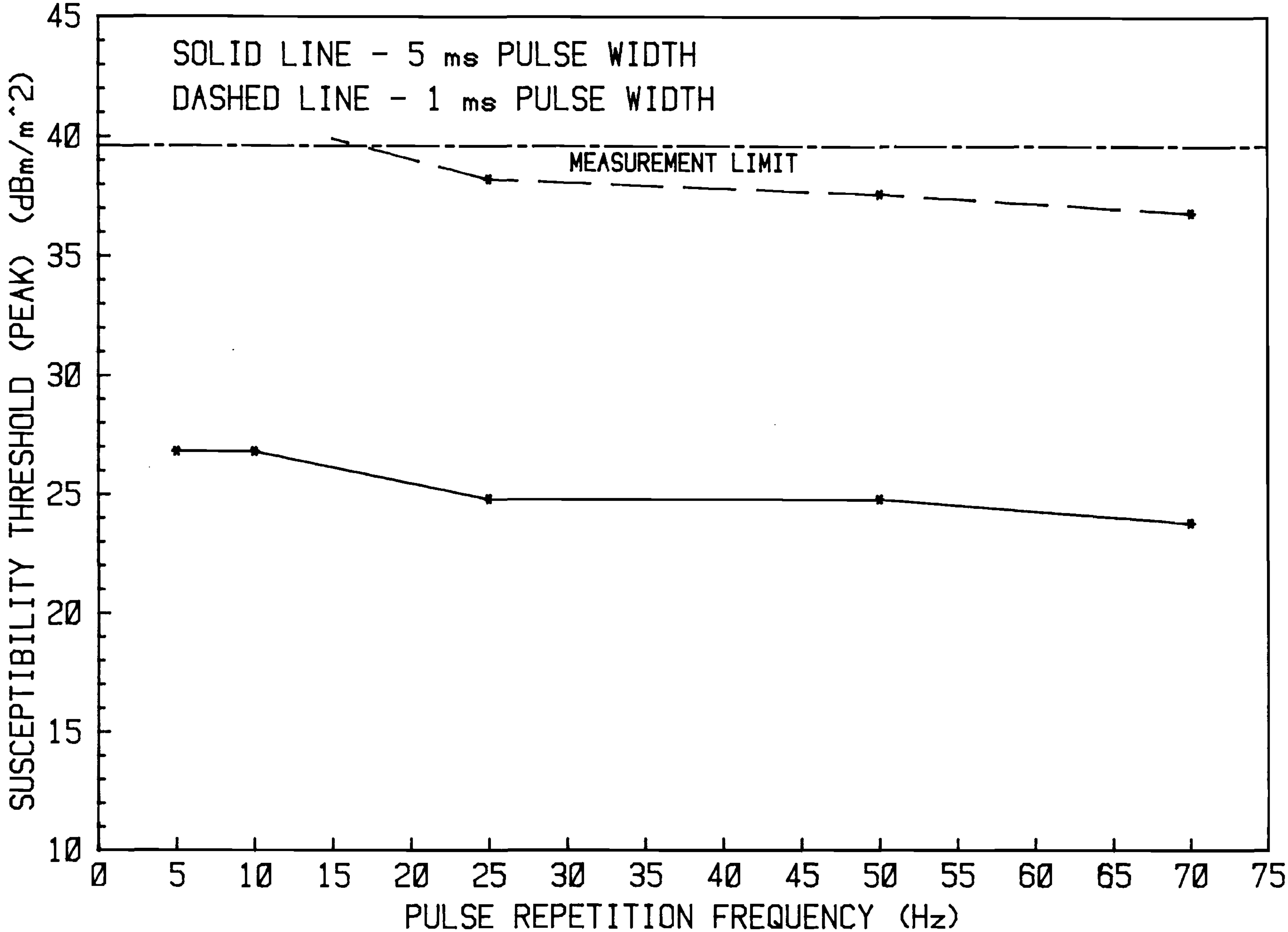

Figure A-4. Radiated Susceptibility Thresholds versus Pulse Repetition Frequency for Receiver Alone -- Channel 8-1-1 (2040 - 2044 kHz).

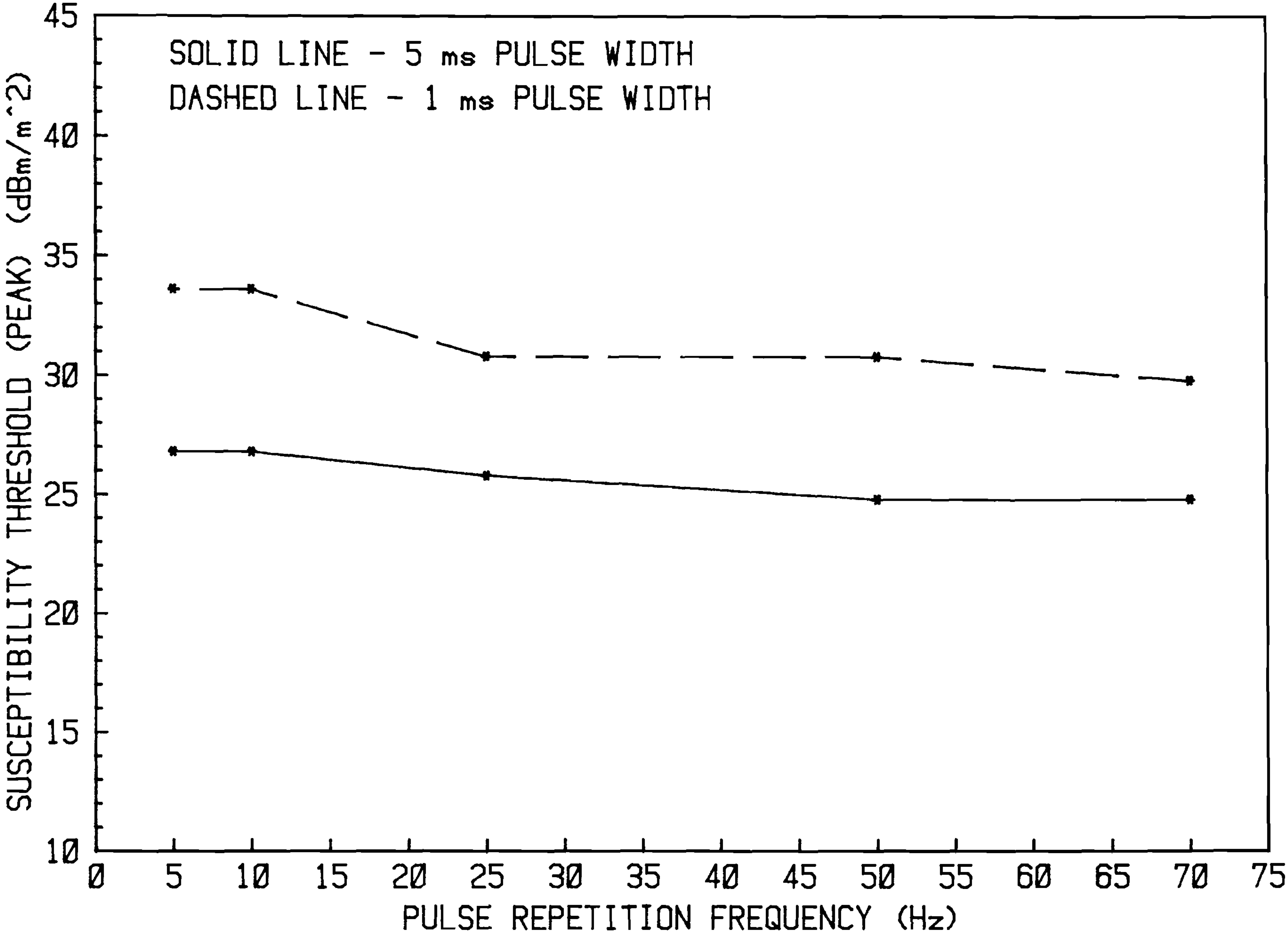

Figure A-5. Radiated Susceptibility Thresholds versus Pulse Repetition Frequency for Receiver Alone -- Channel 10-1-1 (2536 - 2540 kHz).

APPENDIX B

RADIATED SUSCEPTIBILITY THRESHOLDS VERSUS FREQUENCY FOR RECEIVER/MULTIPLEXER TEST CONFIGURATION

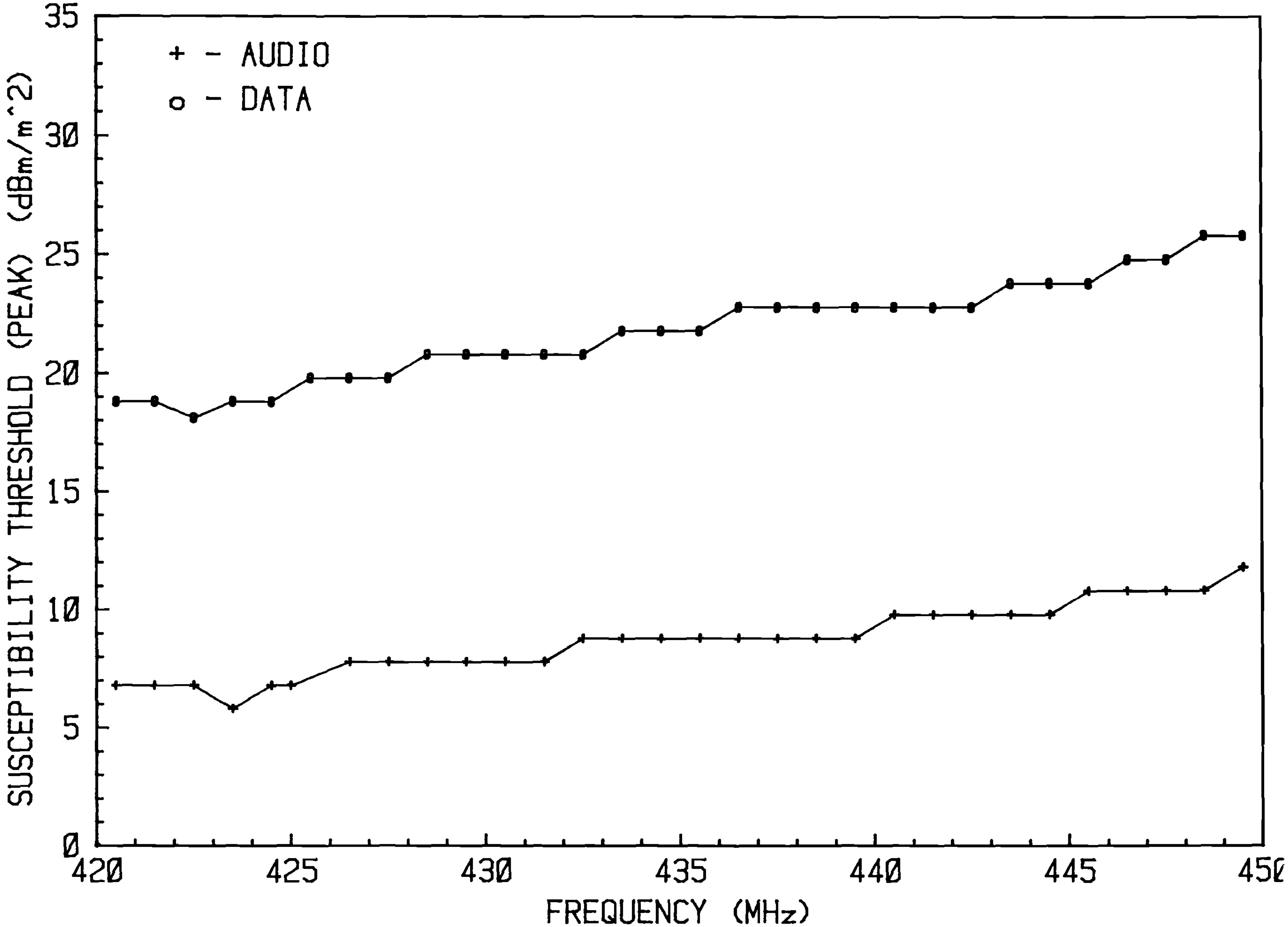

Figure B-1. Radiated Susceptibility Thresholds versus Frequency for Receiver/Multiplexer -- Channel G1 (4 - 9 kHz).

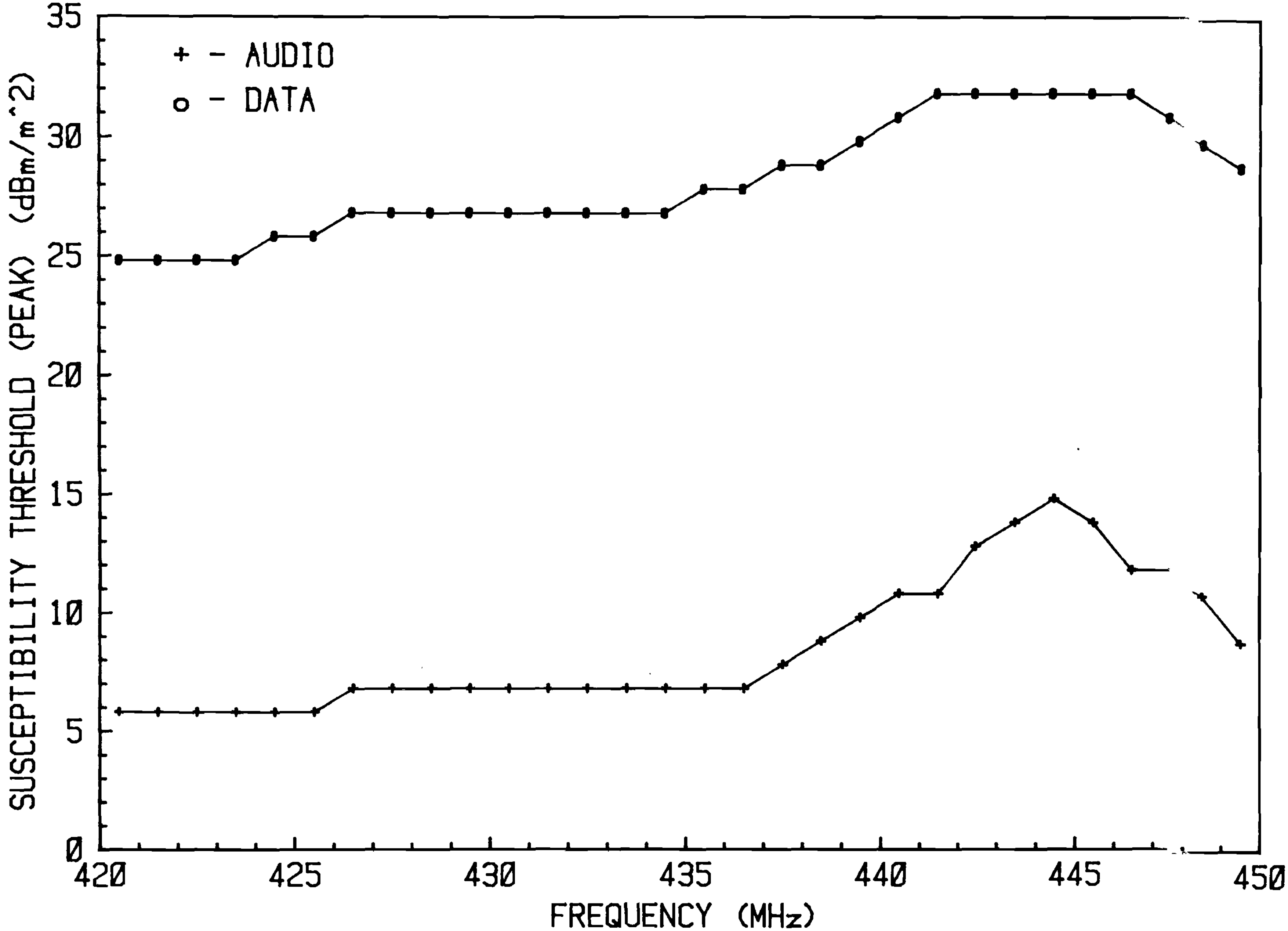

Figure B-2. Radiated Susceptibility Thresholds versus Frequency for Receiver/Multiplexer -- Channel 1-5-12 (60 - 64 kHz).

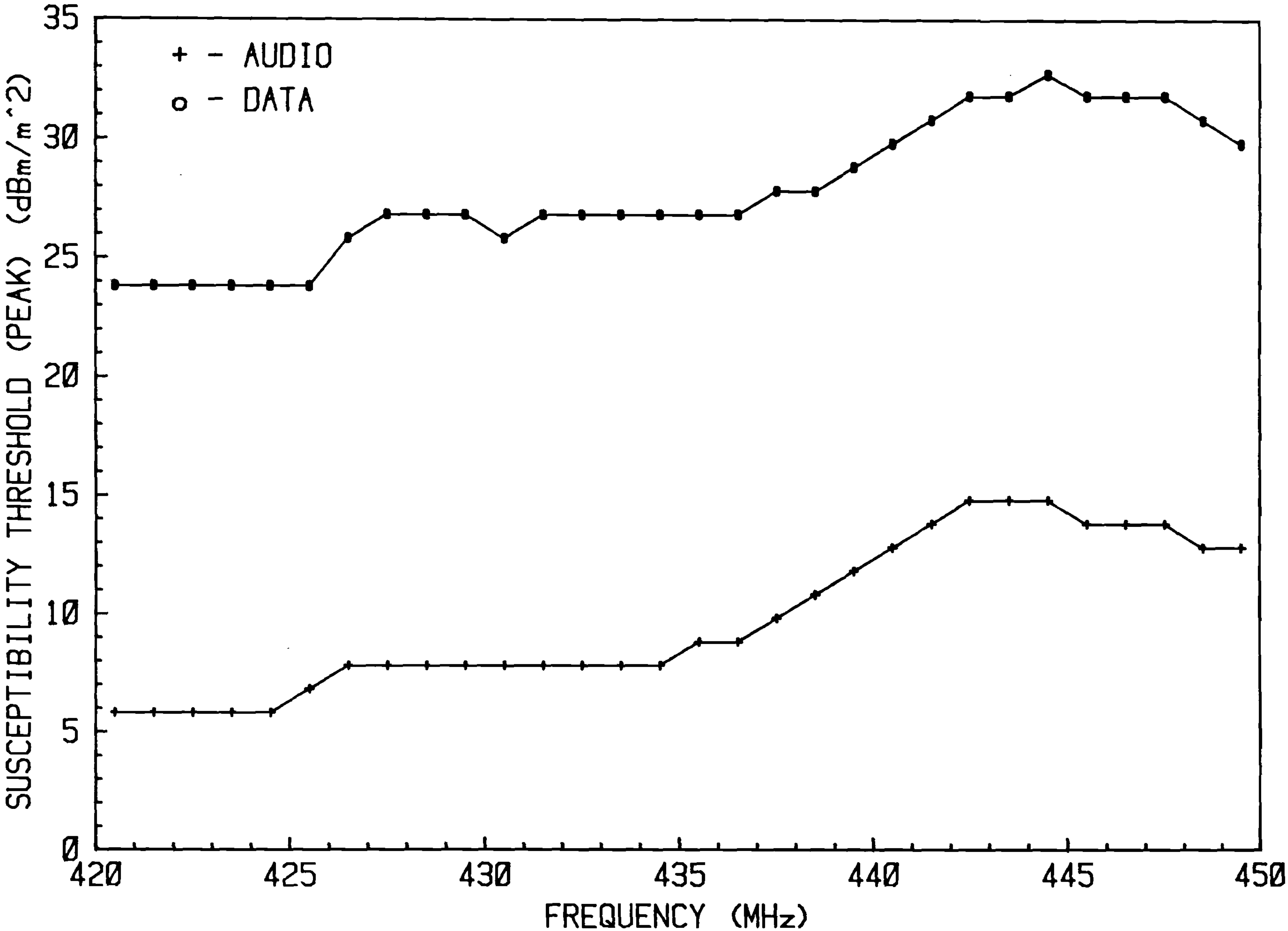

Figure B-3. Radiated Suscpetibility Thresholds versus Frequency for Receiver/Multiplexer -- Channel 5-2-1 (1248 - 1252 kHz).

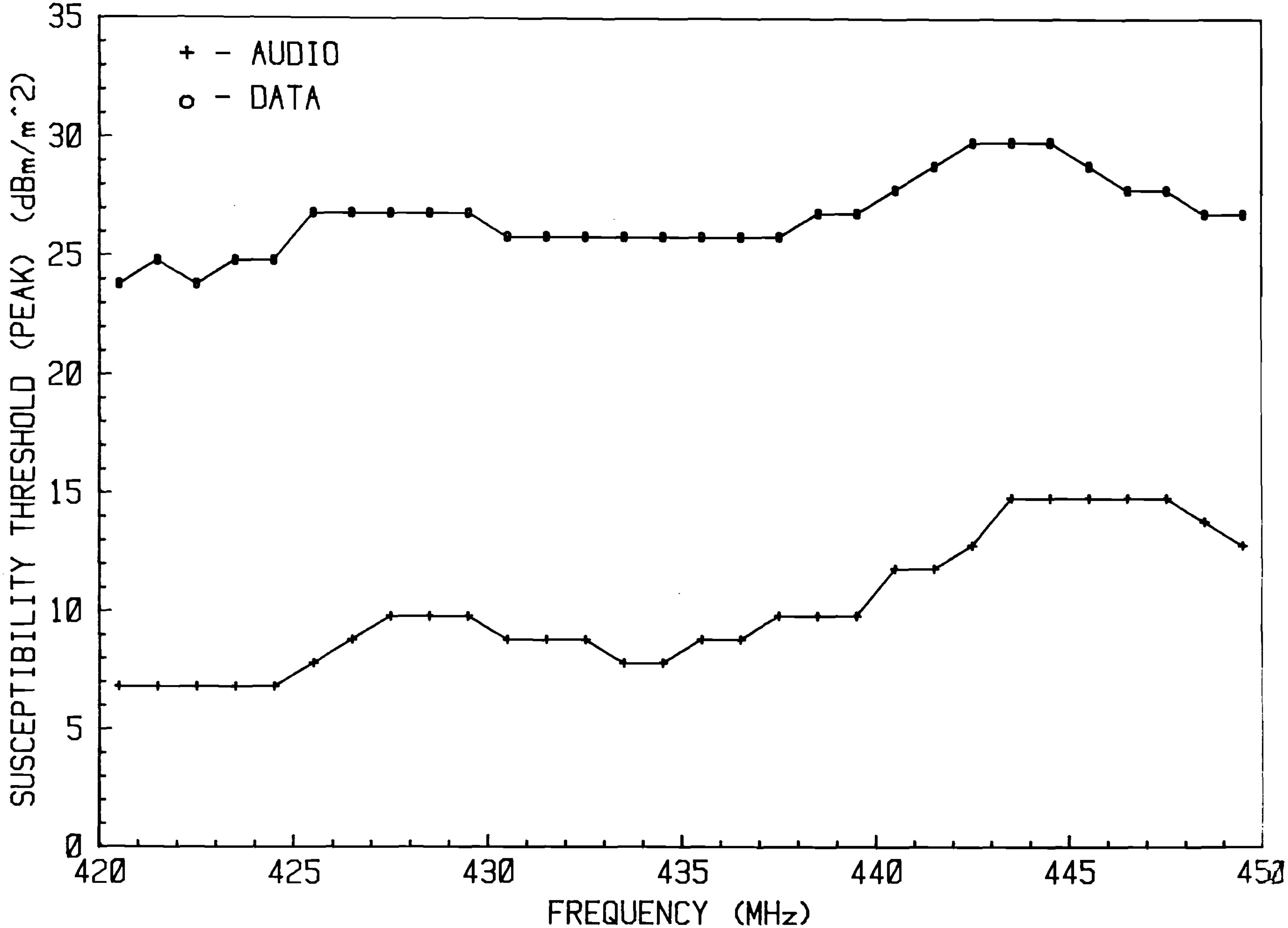

Figure B-4. Radiated Susceptibility Thresholds versus Frequency for Receiver/Multiplexer -- Channel 8-1-1 (2040 - 2044 kHz).

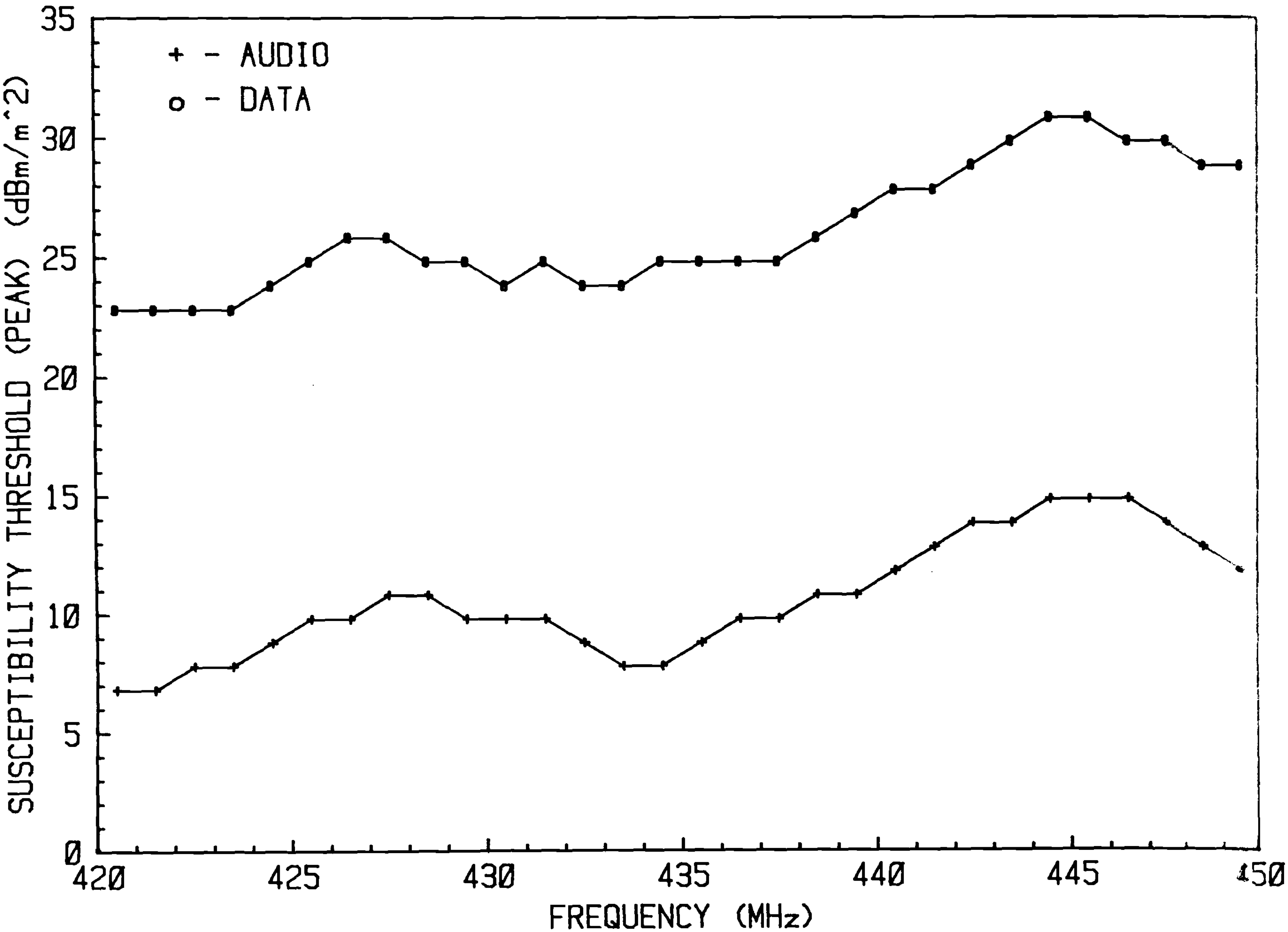

Figure B-5. Radiated Susceptibility Thresholds versus Frequency for Receiver/Multiplexer -- Channel 10-1-1 (2536 - 2540 kHz).

APPENDIX C

EFFECTS OF PULSE REPETITION FREQUENCY ON SUSCEPTIBILITY THRESHOLDS RECEIVER/MULTIPLEXER TEST CONFIGURATION

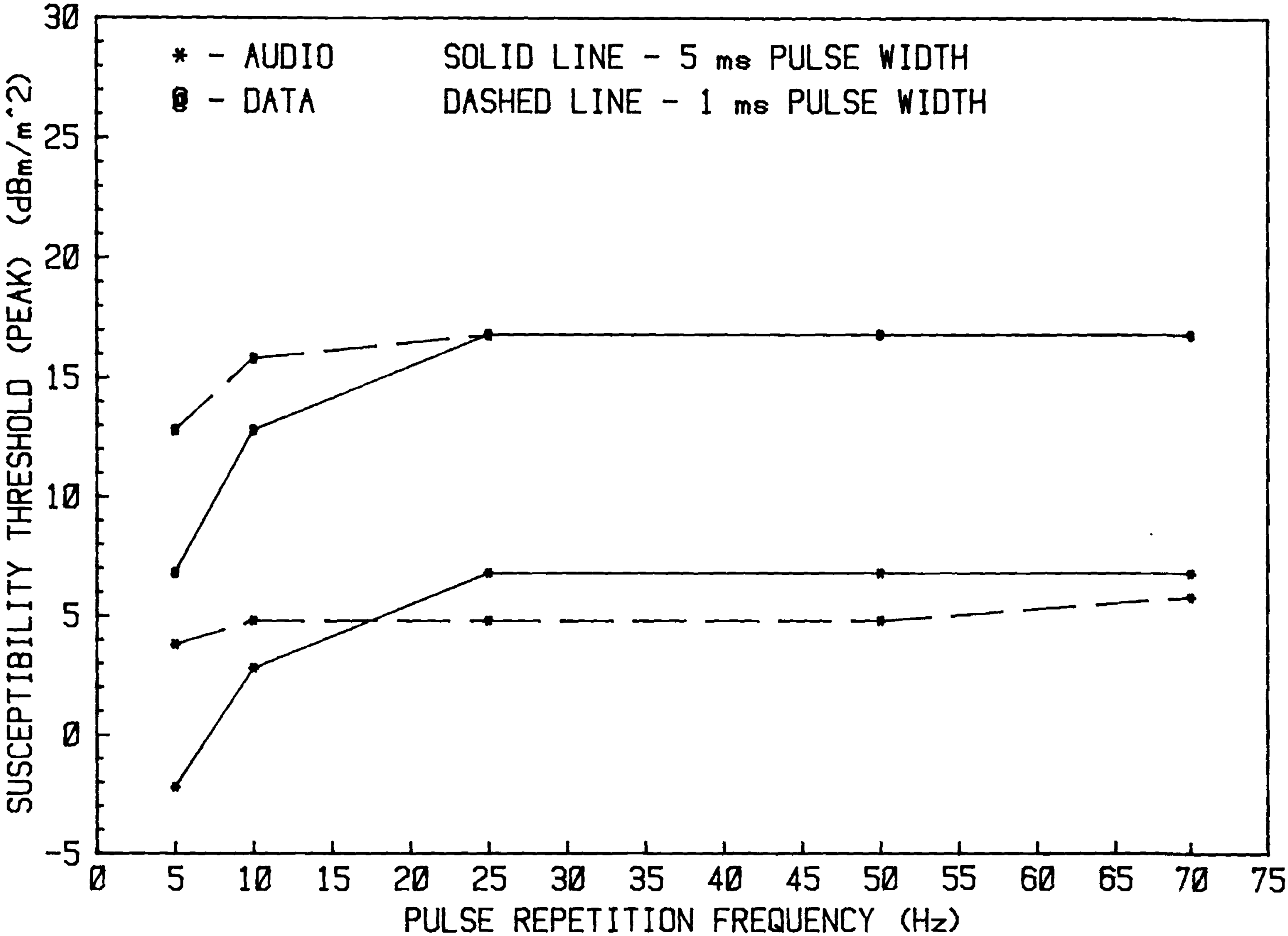

Figure C-1. Radiated Susceptibility Thresholds versus Pulse Repetition Frequency for Receiver/Multiplexer -- Channel G1 (4 - 8 kHz).

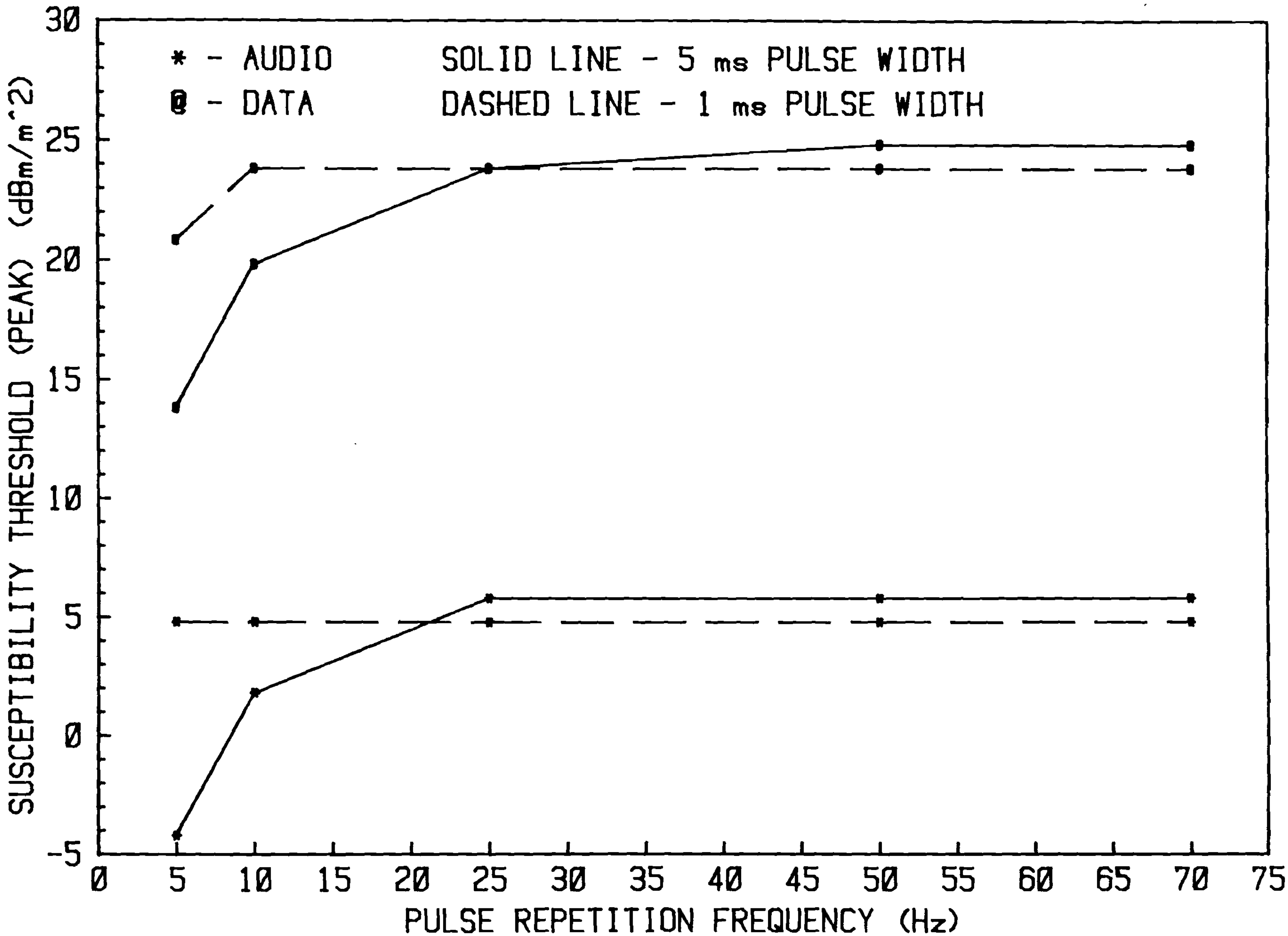

Figure C-2. Radiated Susceptibility Thresholds versus Pulse Repetition Frequency for Receiver/Multiplexer -- Channel 1-5-12 (60 - 64 kHz).

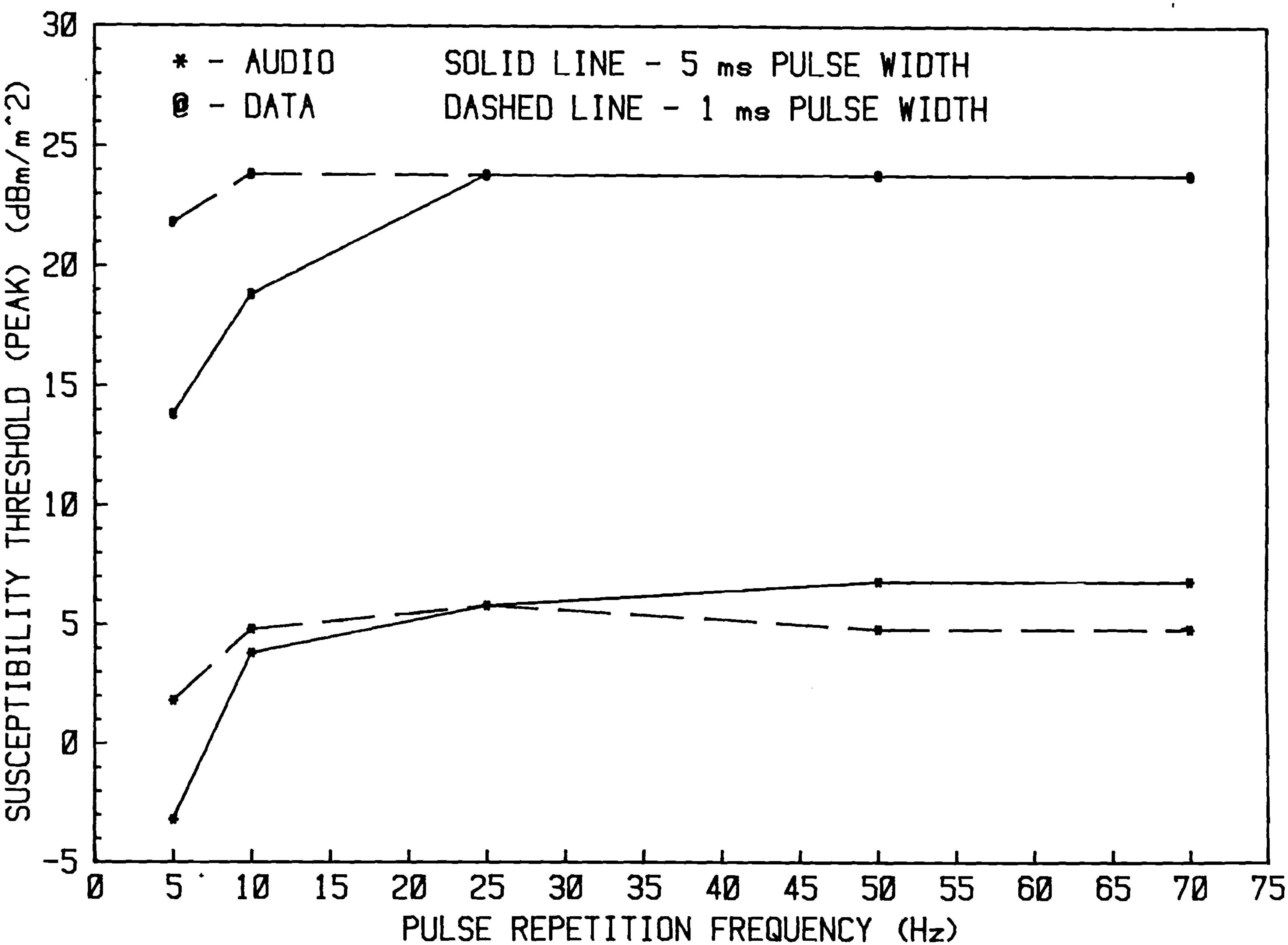

Figure C-3. Radiated Susceptibility Thresholds versus Pulse Repetition Frequency for Receiver/Multiplexer -- Channel 5-2-1 (1248 - 1252 kHz).

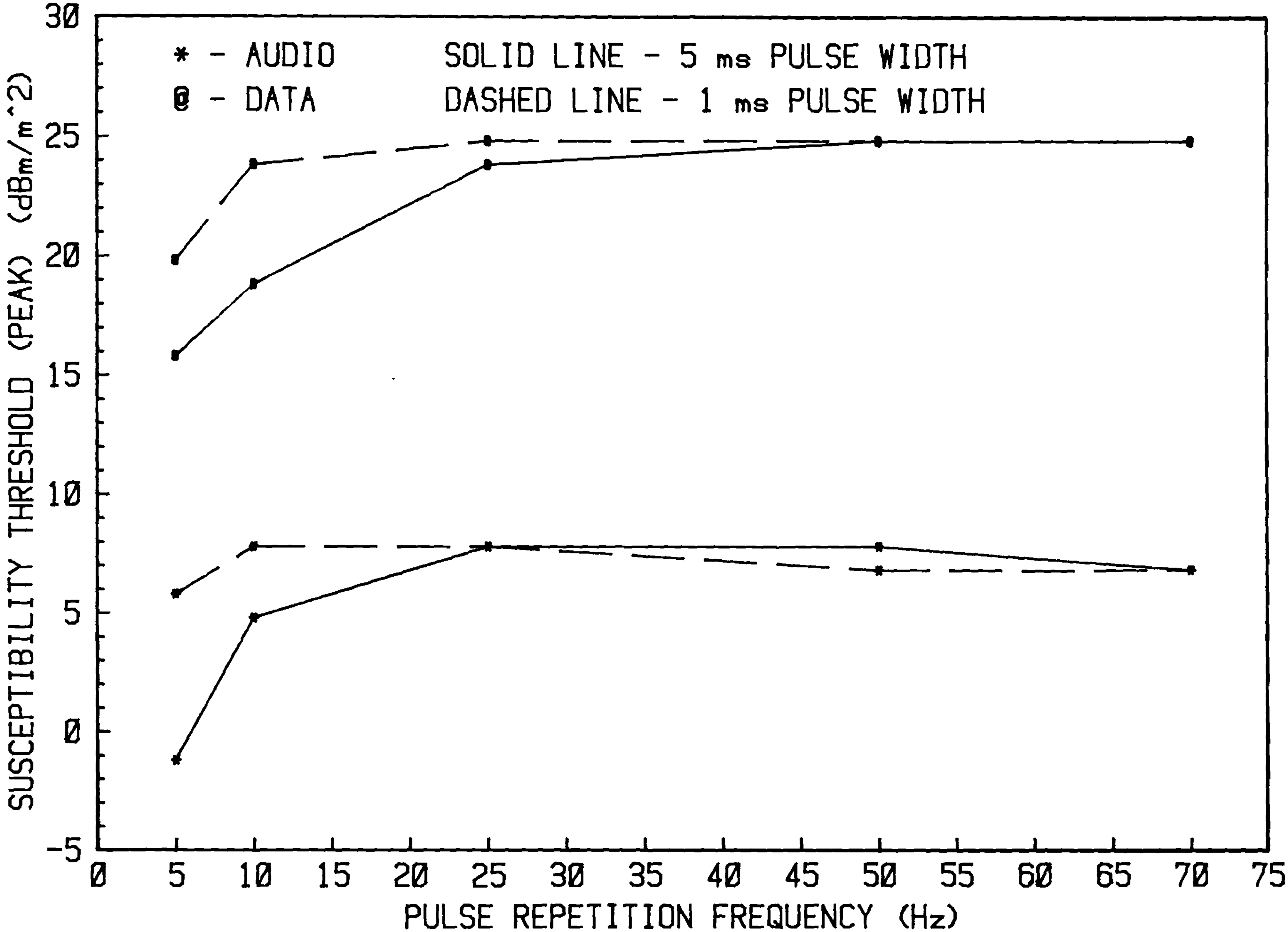

Figure C-4. Radiated Susceptibility Thresholds versus Pulse Repetition Frequency for Receiver/Multiplexer -- Channel 8-1-1 (2040 - 2044 kHz).

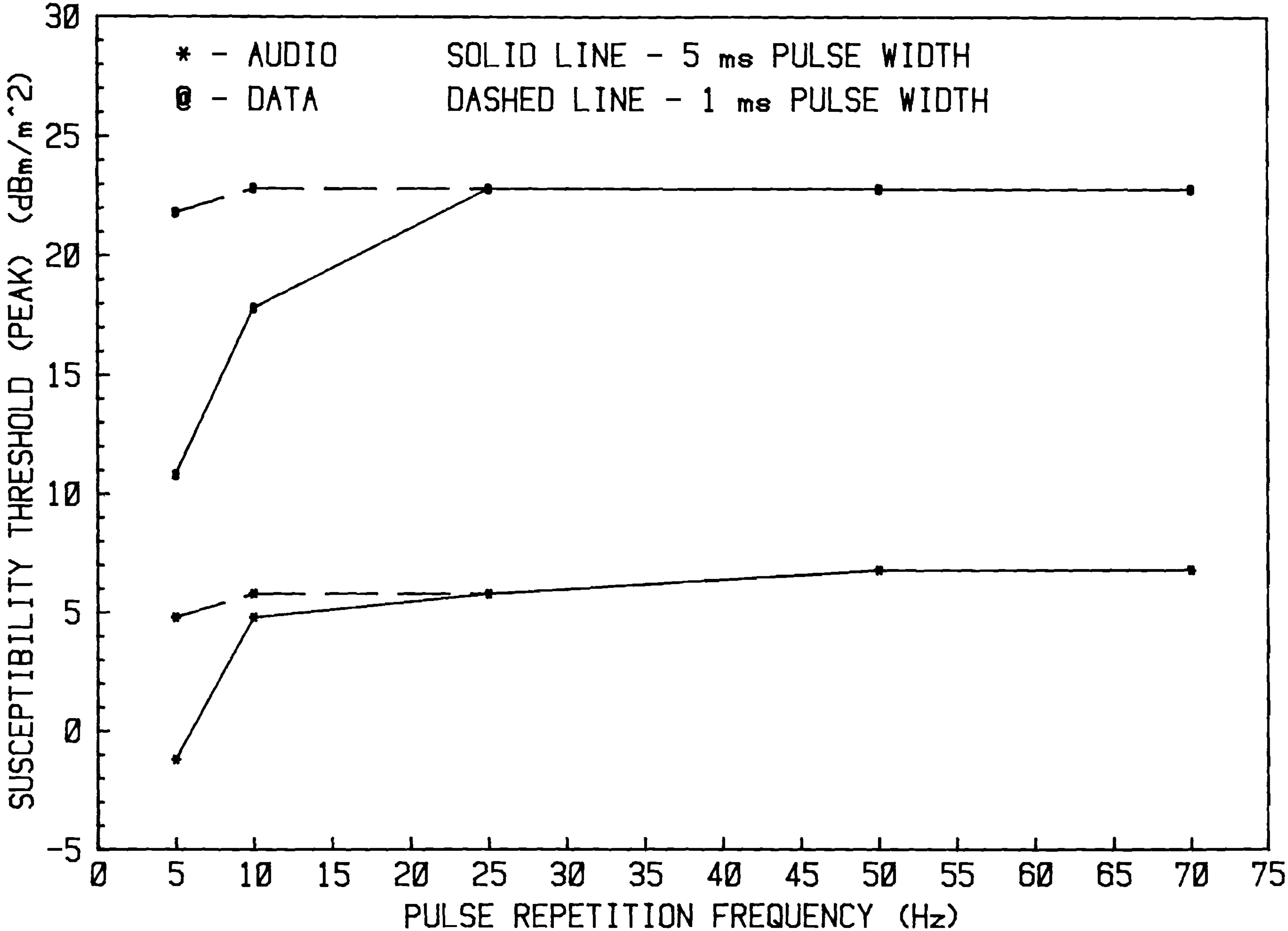

Figure C-5. Radiated Susceptibility Thresholds versus Pulse Repetition Frequency for Receiver/Multiplexer -- Channel 10-1-1 (2536 - 2540 kHz).